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AUTOMATIC INFORMATION PROCESSING AND HIGH PERFORMANCE SKILLS: APPLICATION TO TRAINING

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This report documents a laboratory research effort to investigate the application of automatic processing theory to analogs of complex command and control (C2) operator tasks. Six experiments were performed to investigate complex skill acquisition and transfer of training. The results indicate that elements of automatic processing theory can be applied to training complex task analogs, and suggest that transfer of this training is relatively unaffected by certain changes in the presentation format of information.

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SUMMARY

This document summarizes a research effort investigating automatic processing theory and high performance skills training. Applied training research issues pertaining to skill acquisition and transfer of training were explored with analogs of Command and Control (C2) operator tasks. The results of this work indicate that elements of automatic processing theory can be applied to training of C2 task analogs, and that changes in physical characteristics of the information to be processed have minimal impact on transfer of this training.

PREFACE

The work documented in this report was conducted under Air Force Human Resources Laboratory (AFHRL) Contract No. F33615-88-C-0015 with the University of Dayton Research Institute. This work supports an integrated research program which is developing advanced part-task training techniques based on information processing theory. Captain Michael T. Lawless served as the contract monitor for the Laboratory's Logistics and Human Factors Division (AFHRL/LRG), Wright-Patterson AFB.

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I. INTRODUCTION

Current Air Force Command and Control (C2) systems can require the human operator to rapidly process large volumes of information. Successful use of such systems therefore requires highly skilled operators who can perform under high workload conditions. The high performance skills demanded of operators typically require extensive practice to develop and are characterized by qualitative differences between the novice and expert.

Because of the extensive practice which is required to develop high performance skills, traditional approaches such as on-the-job training can often result in minimally proficient operators. Such training problems demonstrate the need to develop innovative approaches to the acquisition, transfer, and retention of the required high performance skills. Because such skills often represent components of operator functions, part-task training of the high performance elements of skilled performance represents a potentially viable and cost-effective means of developing the required skills.

Application of part-task training to high performance skill development requires an understanding of the components of these skills which can profit most from such training, and specification of the acquisition, transfer, and retention functions that are associated with these components. Automatic/controlled processing theory (e.g., Logan, 1985; Schneider, Dumais, & Shiffrin, 1984; Shiffrin & Schneider, 1977) provides a framework for identifying the critical components of skills (Eggemeier, Fisk, Robbins, Lawless, & Spaeth, 1988) which should be trained.

This theory maintains that with extensive practice, the so-called consistent elements of skill can be automatized, such that they are performed rapidly and effortlessly and with minimal information processing capacity expenditure. Consistently mapped (CM) components of skill are those in which a consistent relationship exists between task elements, such as the stimulus and response. Variably mapped (VM) aspects of skill are those in which the relationship of task elements varies from situation to situation. VM task elements are associated with controlled processing, which is relatively slow and effortful when compared to automatic processing.

Because of their characteristic modes of operation (e.g., fast, relatively capacity-free), automatic processes are of great potential significance to skilled operator performance within Air Force systems. Operator timesharing performance represents one area of possible impact, in that automatic processing of selected task components could represent a means of reducing the loading levels imposed by some current systems (e.g., air weapons control). If the processing requirements of a task component were reduced through automaticity, the freed capacity could possibly be applied to other functions, thereby improving timesharing efficiency. Gains in timesharing efficiency have been demonstrated in several instances in which automatized tasks have been performed at high levels with concurrent controlled tasks (e.g., Fisk & Schneider, 1983; Schneider & Fisk, 1984).

Automatic processes could improve operator performance in a number of other ways as well. As indicated previously, automatic tasks are performed more rapidly than controlled tasks (e.g., Fisk & Schneider, 1983; Hale, 1988). Automatic processes can also result in more accurate (e.g., Myers & Fisk, 1987; Shiffrin & Schneider, 1977) and less variable (e.g., Myers & Fisk, 1987) performance than do controlled processes.

By stipulating that only CM elements of tasks can be automatized and that these components show substantial improvement with practice, dual process theory provides guidelines for training to facilitate development of automatic components of performance. Because CM elements typically (a) require extensive training to develop the characteristics of automatic performance, and (b) show greater improvement than do VM elements, training programs should be structured to permit numerous repetitions and eventual automatization of CM task components.

Automatic processing theory therefore provides both a conceptual framework for skilled performance and guidelines for training to develop automatized components of skilled behavior. Applications of automatic processing principles to train components that will exhibit the noted advantages therefore have the potential to significantly enhance skilled performance within complex Air Force systems.

Despite the potential importance of automatic component processes to the development of high performance skills, there has been little or no work performed to evaluate the applicability of such approaches to Air Force C2 systems. Most laboratory work with consistent task components has, for example, used rather basic materials (e.g., individual letters of the alphabet) and definitions of consistency which are based on individual stimulus-response relationships. These more basic materials and definitions may not apply to the complex environment of the C2 operator. Likewise, data on the transfer of automatic component skills are extremely limited, and must be extended in order to properly evaluate the viability of the automatic processing approach to C2 operator training.

Applications of automaticity to Air Force operator skill acquisition will, therefore, require extensions of current laboratory work in several important areas. Two particularly relevant areas include (a) more extensive specification of the range of task materials and conditions which permit development of automatic processes, and (b) further investigation of the transfer that can be expected -- with automatic processes -- for such materials and conditions.

The current research program was therefore designed to investigate principles of high performance skill acquisition and transfer which are based on the consistent trainable component as specified by automatic processing theory. This report documents a series of experiments that were conducted to examine these two critical issues.

II. ACQUISITION OF AUTOMATIC PROCESSES IN TASKS REQUIRING THE PROCESSING OF SPATIAL PATTERN INFORMATION AND COMPLEX ALPHANUMERIC INFORMATION

Air Force C2 systems (e.g., air weapons control) are characterized by the requirement to rapidly and accurately process a variety of materials such as spatial pattern information and complex alphanumeric sequences (Eggemeier et al., 1988). Much of the initial work with automatic processing (e.g., Schneider et al., 1984) used relatively simple alphanumeric stimuli (e.g., individual letters of the alphabet) in search tasks in which individual targets and distractors remained completely consistent throughout the experiment. Although central to the development of dual process theory, this work did not provide a strong basis for generalizations of the theory to important aspects of skilled performance in Air Force systems.

The purpose of the present experiments was to investigate the development of automatic processing in several tasks requiring the processing of information which was analogous to that required in complex Air Force systems.

As noted above, one very important area for skill development within Air Force C2 systems concerns the rapid and accurate processing of spatial pattern information (Eggemeier et al., 1988). This type of processing is very important for successful performance in systems such as air weapons control, but the development of automaticity with this type of information has not been extensively researched. Some recent work has, however, demonstrated performance differences which are consistent with at least partial automatic processing of such materials (e.g., Eberts

& Schneider, 1986), and has applied training principles derived from automatic processing to tasks involving the processing of spatial information (Schneider, Vidulich, & Yeh, 1982).

Eberts and Schneider (1986), for instance, conducted several studies to determine the effects of extended CM and VM practice on the detection of line segment patterns which were presented sequentially on several channels of a visual display. A number of advantages of CM over VM conditions that were consistent with the development of at least partial automaticity were noted at the conclusion of practice. CM targets, for instance, were detected more reliably than were VM targets, and maintained that advantage when the number of channels to be monitored was increased.

An additional important application of automaticity for high performance skills training is to the processing of complex alphanumeric materials. In some instances, operators of Air Force C2 systems (e.g., air weapons control) must search a display for alphanumeric patterns (e.g., acronyms representing system parameters or aircraft), and automatic processing of this type of information is an important aspect of performance in these systems.

Although no direct work has been reported with the type of three- or four-letter acronyms that must be processed by Air Force system operators, Myers and Fisk (1987) conducted a series of experiments which support the applicability of automatic processing to such materials in a laboratory analog of a telecommunications industry job. Subjects were required to search fields in a display for patterns defined by the conjunctions of letters of the alphabet. After equivalent amounts of practice, CM patterns were detected more rapidly and accurately than were VM targets, and performance in the CM conditions remained invariant with increases in the size of the search set. These results therefore indicate that the benefits of automatic processing can accrue to certain forms of complex alphanumeric materials.

Results of recent research with spatial and complex alphanumeric materials therefore suggest that characteristics of automaticity that had been identified with relatively simple materials do, in fact, generalize to materials that are more representative of those which must be processed by operators of complex systems. Some results do, however, suggest that important limits may exist on the degree of automaticity that can be achieved under certain situations. The Eberts and Schneider (1986) research, for example, raises important issues regarding the degree of automaticity that can be developed when target patterns are spatial in nature, when such patterns are composed of sequentially presented elements, or when the stimuli to be processed are highly confusable. The capability to achieve only partial forms of automaticity under such conditions is of great potential importance in applications to Air Force C2 systems, as these systems would typically impose such conditions on operator performance.

One major objective of the current effort was to investigate the development of automatic processing in tasks which impose processing requirements that are similar to those involved in Air Force C2 systems. Given the importance of spatial pattern and complex alphanumeric information to such systems and the relatively little automatic processing work conducted with these types of information, additional investigations were required in order to examine the development of automatic processing in these areas.

Therefore, the following three experiments were performed in order to investigate levels of performance that could be achieved with extended training in tasks requiring the processing of spatial pattern information and complex alphanumeric information. Experiment 1 examined the effects of training on a task which required that subjects search for spatial patterns that were representative of those which must be processed in several Air Force systems. Experiments 2 and 3 examined the effects of extended practice on three-letter acronyms of the type that must be processed by operators of some Air Force information systems.

Experiment 1
Development of Automatic Processing in a Spatial Pattern Identification Task

Purpose

The purpose of this experiment was to investigate the levels of performance which could be achieved in both CM and VM conditions in a memory search task that required the processing of spatial pattern information. The memory search task was chosen for this application, because it requires that subjects maintain a variable number of target or critical patterns in memory, and rapidly and accurately determine if a probe pattern is a member of the critical or memory set. Critical or so-called target patterns require a rapid positive response, whereas non-target or distractor patterns require a negative response. This type of memory search -- one that requires one type of response to a target subset and another type of response to a non-target subset -- is associated with important operator functions in several C2 systems, such as event detection. In performing the event detection function, an operator is typically required to respond positively to the occurrence of a subset of target events, and to respond in a different manner to the occurrence of non-target or distractor events. Because of its similarity to a component of important operator functions in C2 systems, the memory search task was considered ideal to investigate the capability of subjects to achieve some degree of automatic processing with spatial pattern information.

As noted above, Eberts and Schneider (1986) had conducted a series of experiments with dynamic spatial patterns which required the integration of pattern elements over time, and these experiments had resulted in evidence of partial automaticity. Several types of Air Force systems require the recognition and detection of dynamic spatial pattern information, but it is typical for at least several elements of these patterns to be present on the system display at one time (Eggemeier et al., 1988). Therefore, demands on short-term memory to retain pattern elements in these systems can be somewhat less than the load which was apparently imposed in the Eberts and Schneider (1986) work.

Therefore, Experiment 1 was conducted in order to initially explore the development of automatic processing in spatial patterns that were similar to those required by some Air Force systems, but which did not impose the requirement to integrate pattern elements over time. In order to minimize possible confusion between spatial patterns, three sets of such patterns were developed in order to represent three classes of aircraft or vehicle movement which are presented in some Air Force C2 systems.

Method

Subjects. Subjects were 12 University of Dayton students. They were paid $4.00 per hour for their participation. In addition to this base rate of pay, subjects were awarded a bonus payment of $1.00 per hour for appearing on time for each scheduled experimental session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer was programmed to present stimuli, control the timing of stimulus presentation, and collect subject responses. Subjects viewed spatial pattern stimuli on a Zenith ZCM-1490 high-resolution color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance levels was presented to subjects through Realistic Nova-16 headphones.

Procedure. Subjects performed a memory search task which was modeled after the Sternberg (1966) paradigm. On each trial, subjects were shown a memory set of one to four spatial patterns on the computer cathode-ray tube (CRT) screen. These spatial patterns remained on the screen until the subject pressed a designated key on a computer keyboard. At this point, a fixation cross 4.5 millimeters (mm) in height and 4.3 mm in width appeared in the middle of the screen for 500 milliseconds (ms). The fixation cross was replaced by a single test pattern which was displayed for a maximum of 2 seconds or until the subject responded.

The subject was instructed to rapidly determine whether or not the test pattern was a member of the previously presented memory set. Subjects responded "yes" or "no" by pressing with their preferred hand a labeled response button on the keyboard. One-half of the target patterns in each block of trials were members of the memory set; the other patterns were not members of the set. Two dependent measures, reaction time and response accuracy, were collected. Each subject was encouraged to respond as rapidly as possible while maintaining an accuracy level of 90% or higher within each session.

Visual and auditory feedback were provided to subjects at the completion of each trial. After each trial, an incorrect response was followed by a "Wrong Response" message on a red background, and by a tone. A correct response was followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence for those reaction times that were below a specified criterion. In addition, the feedback concerning correct responses also included a message specifying the level of performance indicated by the reaction time that had been achieved. This feedback indicated to the subject if the level was that of a "Novice," "Professional," "Expert," or "Ace." These levels represented progressive decreases in reaction time to the spatial pattern information, and the feedback encouraged the subject to attempt to lower reaction time if only the "Novice" level had been achieved on a particular trial. Performance categories were based on reaction times achieved by subjects in a pilot study which preceded the present experiment.

Additional summary feedback was provided at the beginning of each day of training following the initial training day. This feedback summarized reaction time and accuracy performance levels from each of the previous training days, and provided a means for subjects to follow changes in their performance as a function of training.

Subjects participated in the experiment for a total of 5 days. On each day, subjects completed four 30-minute training sessions which consisted of 10 blocks of 20 trials each. Therefore, there were 800 training trials each day and a total of 4,000 training trials across the experiment.

Stimulus Materials. Each spatial stimulus pattern was composed of five circular elements, and was intended to represent the type of pattern processed by operators of certain Air Force systems. These systems require the operator to identify spatial patterns associated with the movement of targets that are represented by dot patterns which progressively move across the system display with elapsed time. Three principal patterns of movement are typical with such targets: (a) constant movement represented by equal spacing between pattern elements, (b) accelerated movement represented by progressive increases in the spacing between pattern elements, and (c) decelerated movement represented by progressive decreases in the spacing between pattern elements.

In order to represent these major patterns of target movement, three sets of static spatial pattern stimuli --

composed of four stimuli each -- were developed. One set of stimuli was designed to represent constant target movement, the second set was designed to represent accelerated target movement, and the third set was designed to represent decelerated target movement. Four patterns were included in each set, and represented (a) a target that involved no turn, (b) a target that involved a turn at the beginning of the represented sequence, (c) a target that involved a turn at the completion of the represented sequence, and (d) a target that involved a turn at both the beginning and completion of the sequence. Examples of the patterns used are provided in Appendix A.

Design. Three independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training sessions. Target/distractor mapping was either CM or VM, and represented a between-subjects variable. Six subjects were assigned to the CM group and six subjects to the VM group. In the CM condition, one set of spatial patterns served as targets throughout training for an individual subject, and a second set served as distractor patterns. In the VM condition, sets of target patterns served as both targets and distractors across blocks of trials. The three sets of spatial pattern stimuli were distributed such that each set served an equal number of times as targets and distractors in the CM condition and as targets/distractors in the VM condition. Memory set size was manipulated within blocks of trials in each group, and consisted of one to four spatial patterns. Each group completed 20 sessions of practice trials across the 5 days of training.

Results

Reaction Time. Mean reaction time to test patterns as a function of CM/VM condition and training sessions is illustrated in Figure 1. The means depicted in Figure 1 are based on correct responses by subjects. As is clear from the figure, both CM/VM condition and sessions had a substantial effect on reaction time. Reaction times were consistently lower in the CM group than in the VM group, and also improved in both groups as a function of training.

A 2 x 4 x 20 Analysis of Variance (ANOVA) was performed on the reaction time data in order to analyze the effects of mapping condition (CM vs. VM), memory set size (1-4), and training session (1-20). Mapping condition was a between-subjects variable in this analysis, while memory set size and training session were within-subjects variables. This analysis indicated that the main effects of mapping condition [$F(1,10) = 11.13$, $p < .009$], memory set size [$F(3,30) = 76.36$, $p < .001$], and training sessions [$F(19,190) = 53.52$, $p < .001$] were significant. The interactions of CM/VM and memory set [$F(3,30) = 23.94$, $p < .001$], memory set and session [$F(57,570) = 6.73$, $p < .001$], and CM/VM x memory set x session [$F(57,570) = 1.68$, $p < .003$] were also significant.

The main effect of CM/VM mapping condition is consistent with the development of some degree of automatic processing in the CM condition, in that reliably faster responses were exhibited in the CM condition as compared with the VM condition. The significant improvement in performance with training and the effect of memory set size on reaction time are consistent with previous work (e.g.,

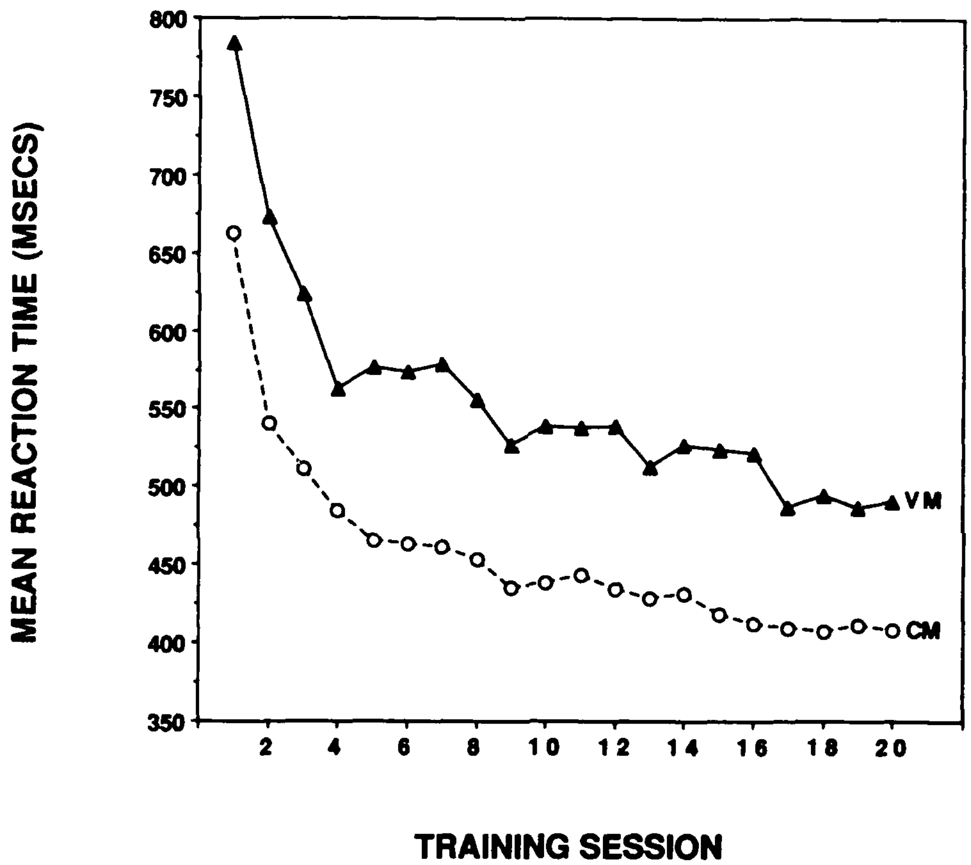


Figure 1. Mean Reaction Time as a Function of Mapping Condition and Training Session - Experiment 1.

Fisk & Schneider, 1983) with the same memory search paradigm with different materials. Therefore, the main effects are consistent with expectations and with the development of automatic processing in the CM group.

As noted above, one criterion used in assessing the development of automatic processing is the response time advantage of the CM group over the VM group. A second criterion which can be applied to test the development of automatic processing is a greater reduction in the effect of task demand within the CM group versus the VM group as training progresses. Within the current memory search task, task demand was varied through manipulations of memory set size. Therefore, a reduction in the effect of memory set size in the CM versus the VM group with training represents a second criterion that can be applied in the current study to assess the development of automatic processing with the present spatial patterns. The significant CM/VM x memory set x training session interaction reported above is consistent with the development of a differential effect of memory set size within the CM and VM groups with training.

Figure 2 shows the effect of memory set size on reaction time in the CM and VM groups for both the first and last sessions of training. As is clear from the figure, memory set size had a substantial effect on both CM and VM performance during the first training session. At the conclusion of training, however, the effect of memory set on reaction time had been markedly attenuated in the CM group, while set size continued to show a strong effect on VM group performance. In order to characterize the reductions in memory set size on performance in each group, slopes of the functions depicted in Figure 2 were computed. Within the CM

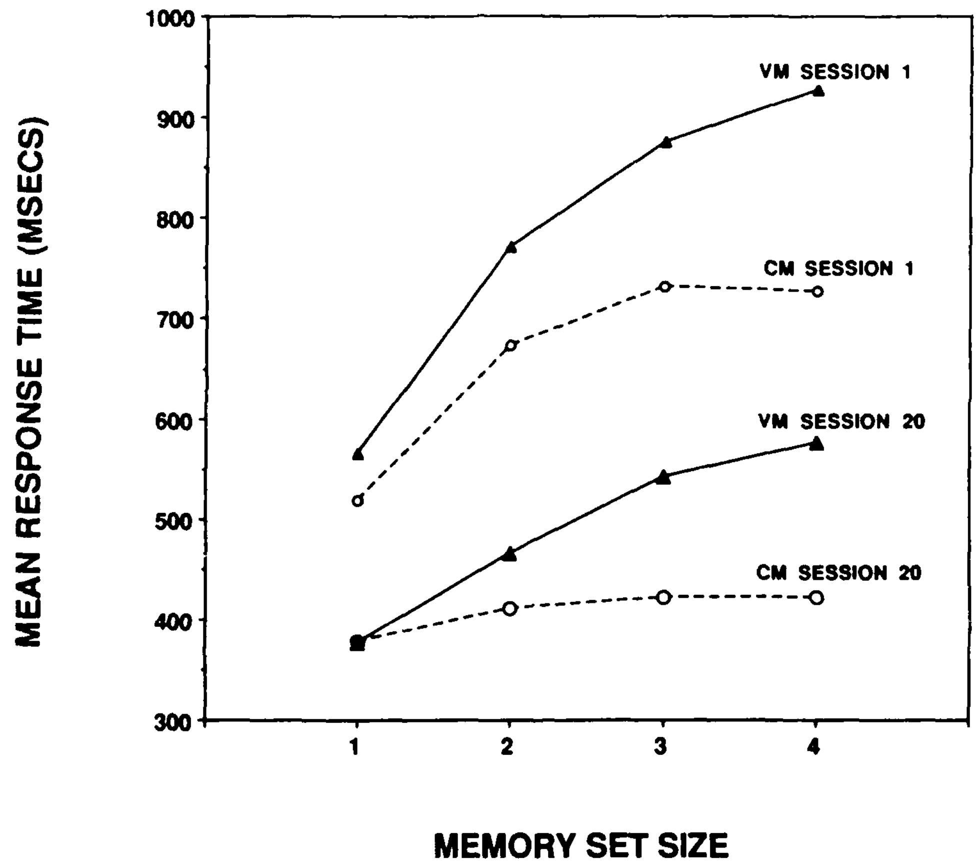


Figure 2. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size and Training Session - Experiment 1.

group, the slope of the Session 1 function was 69.08 ms, and the slope of the Session 20 function was 14.24 ms. In the VM group, however, the slope of the Session 1 function was 118.81 ms, and was reduced to 67.70 ms by Session 20. Therefore, the CM group showed a 79% reduction in slope with training as compared to a 43% reduction in slope in the VM group. Once again, this type of CM-VM difference is consistent with the development of automatic processing in the CM group.

Accuracy of Responding. Figure 3 shows mean percent correct responses as a function of CM/VM group and training session. As is clear from the figure, response accuracy was consistently high, and improved in both groups as a function of training.

A 2 x 4 x 20 ANOVA which was comparable to that performed on the reaction time data was conducted on the percent correct responses. This analysis demonstrated no main effect of mapping condition [$F(1,10) = 0.54$, $p > .45$], a significant main effect of memory set size [$F(3,30) = 11.46$, $p < .001$], and a reliable effect of training sessions [$F(19,190) = 2.56$, $p < .002$]. The CM/VM x memory set interaction [$F(3,30) = 2.97$, $p < .048$] was reliable, but all other interactions proved to be non-significant. The main effect of memory set size reflects increased error rates in both groups as memory set size increased, and the main effect of training session confirms the trend for increased accuracy in both mapping groups as a function of training as noted in Figure 3. The failure to find significant CM versus VM differences indicates that the difference in reaction times noted in Figure 1 cannot be attributed to a significant speed-accuracy tradeoff, and therefore is

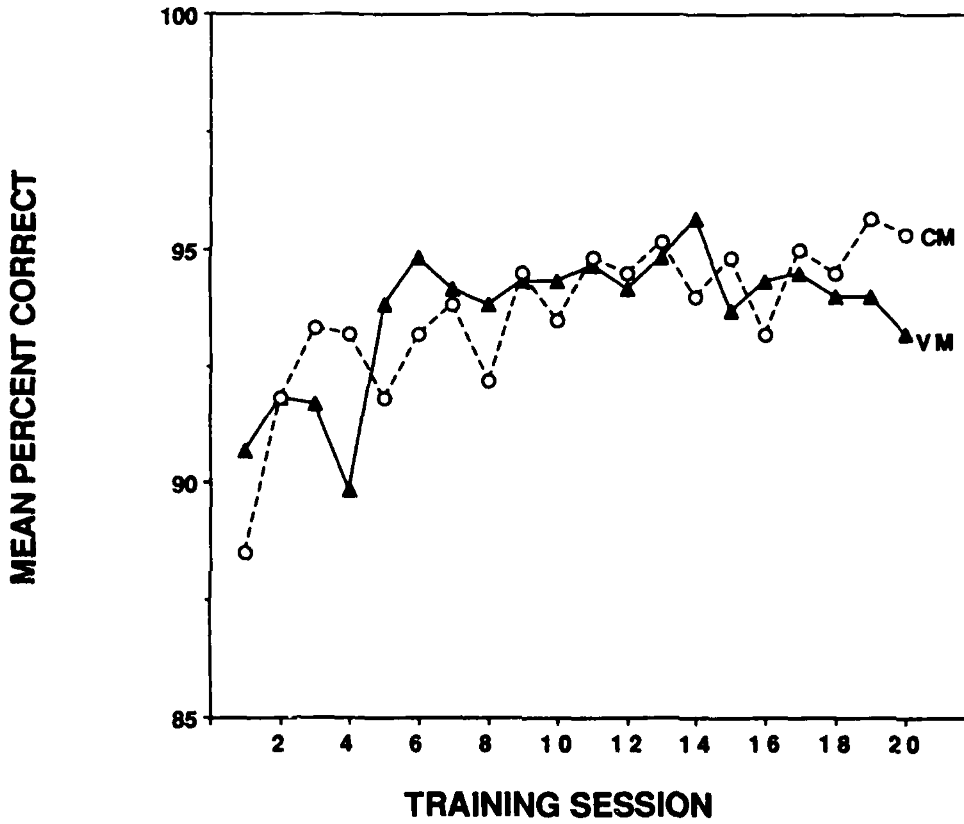


Figure 3. Mean Percent Correct as a Function of Mapping Condition and Training Session - Experiment 1.

consistent with the interpretation of reaction time differences as supporting the development of automatic processing in the CM group.

Experiment 2
Development of Automatic Processing in a Task Requiring the Processing of Complex Alphanumeric Information With Dissimilar Target and Distractor Sets

Purpose

In addition to the spatial pattern information investigated in Experiment 1, some Air Force C2 systems require the operator to rapidly process complex alphanumeric information such as multiple-letter sequences. These sequences of letters can stand for various system parameters or aircraft, and must be rapidly and accurately identified under certain conditions by operators in order to access information from system displays. Although the capability to automatize the processing of such letter sequences is of great potential importance to operators of C2 systems, little information is available in the current literature to address automatic processing of such complex alphanumeric materials.

Therefore, the purpose of Experiment 2 was to investigate the development of automatic processing with this second type of information which must be processed by Air Force system operators. This experiment employed the same memory search paradigm as that used in Experiment 1. As indicated previously, this type of memory search is a component of many operator tasks in air weapons control and critical event detection systems, and requires rapid and accurate responding. The memory search task in this experiment used target and distractor sets which consisted of three-letter sequences (e.g., SNK, GLX) that were dissimilar and therefore highly distinguishable from one another.

Method

Subjects. Subjects were 32 University of Dayton students. They were paid $4.00 per hour for their participation. In addition to this base rate of pay, subjects were awarded a bonus payment of $1.00 per hour for appearing on time for each scheduled experimental session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer presented stimuli, controlled the timing of stimulus presentation, collected subject responses, and presented visual and auditory feedback after each trial. Subjects viewed spatial pattern stimuli on a Zenith ZCM-1490 high-resolution color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance levels was provided to each subject through Realistic Nova-16 headphones.

Procedure. Subjects performed a memory search task similar to the Sternberg (1966) paradigm. On each trial, a memory set of one- to four-letter sequences was presented on the computer CRT screen. These letter sequences remained on the screen until the subject pressed a designated key on a computer keyboard. When the key was pressed, a 4.5 mm x 4.3 mm fixation cross appeared in the middle of the screen for 500 ms. The fixation cross was replaced by a single test sequence, which was displayed for a maximum of 2 seconds or until the subject responded.

Subjects were instructed to determine if the test sequence had been a member of the previously presented memory set. Subjects responded "yes" or "no" by pressing with their preferred hand a labeled response button on the keyboard. One-half of the target stimuli in each block of trials were drawn from the memory set; the other stimuli were not. Measures of both reaction time and response accuracy were recorded. Each subject was instructed to respond as rapidly as possible while maintaining an accuracy level of 90% or higher within each session.

Visual and auditory feedback were provided to subjects at the completion of each trial. After each trial, an incorrect response was followed by a "Wrong Response" message on a red background, and a tone. A correct response was followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence for those reaction times which were below the specified criterion of 400 ms.

Summary feedback was provided at the completion of each session. This feedback summarized reaction time and accuracy performance levels from each of the previous training sessions, and permitted subjects to follow changes in their performance as a function of training. In addition to summary feedback, subjects were also given information that permitted them to determine which of four levels of proficiency had been achieved during each session. These levels were based on reaction times and assumed that the subject had maintained the criterion of no more than 10%

errors. As in the previous experiment, the levels were "Novice," "Professional," "Expert," and "Ace," with the latter representing the most proficient level of performance.

Subjects participated in the experiment for a total of 4 days. Four training sessions, which consisted of 10 blocks of 20 trials each, were completed each day. This resulted in 800 training trials each day and a total of 3,200 training trials for the entire experiment.

Stimulus Materials. Each letter sequence contained three letters, and was intended to represent the type of complex alphanumeric information processed by operators of certain Air Force systems. As noted above, these systems require the operator to rapidly and accurately process alphanumeric sequences associated with particular aircraft or system parameters.

Four sets of letter sequences composed of four stimuli each were chosen from the 50% association value letter sequences in the Underwood and Schultz (1960) norms. Sequences in each set were chosen to be highly distinguishable from one another, such that no sequence included a letter that appeared in the same serial position in another sequence. Therefore, the first, second, and third letter of each sequence differed from the letters in the corresponding serial position in the other sequences. These sets of sequences were therefore chosen to minimize any similarity or potential confusability between target and distractor items. For purposes of use during CM conditions, two sets were designated as target sets and two sets as distractor sets. Exactly the same letter sequences were used in VM conditions, except that the target/distractor set distinction was not relevant. Examples of the letter sequences used are provided in Appendix B.

Design

Three major independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training sessions. Target/distractor mapping was either CM or VM, and represented a between-subjects variable. Sixteen (16) subjects were assigned to the CM group and 16 subjects to the VM group. In the CM condition, one set of sequences served as targets throughout training for an individual subject, and a second set served as distractor patterns. In the VM condition, sets of target sequences served as both targets and distractors across blocks of trials. The sets of sequences were distributed such that each target and distractor set served an equal number of times as targets and distractors respectively in the CM condition, and as targets/distractors in the VM condition. Within each target/distractor mapping group, one-half of the subjects were presented with sequences in uppercase letters, and the other half were presented with sequences in lowercase letters. Memory set size was manipulated within blocks of trials in each group, and consisted of one to four sequences. Each group completed 16 sessions of practice trials across the 4 days of training.

Results

Reaction Time. Mean reaction time to test stimuli as a function of CM/VM condition and training sessions is illustrated in Figure 4. The means presented in Figure 4 are

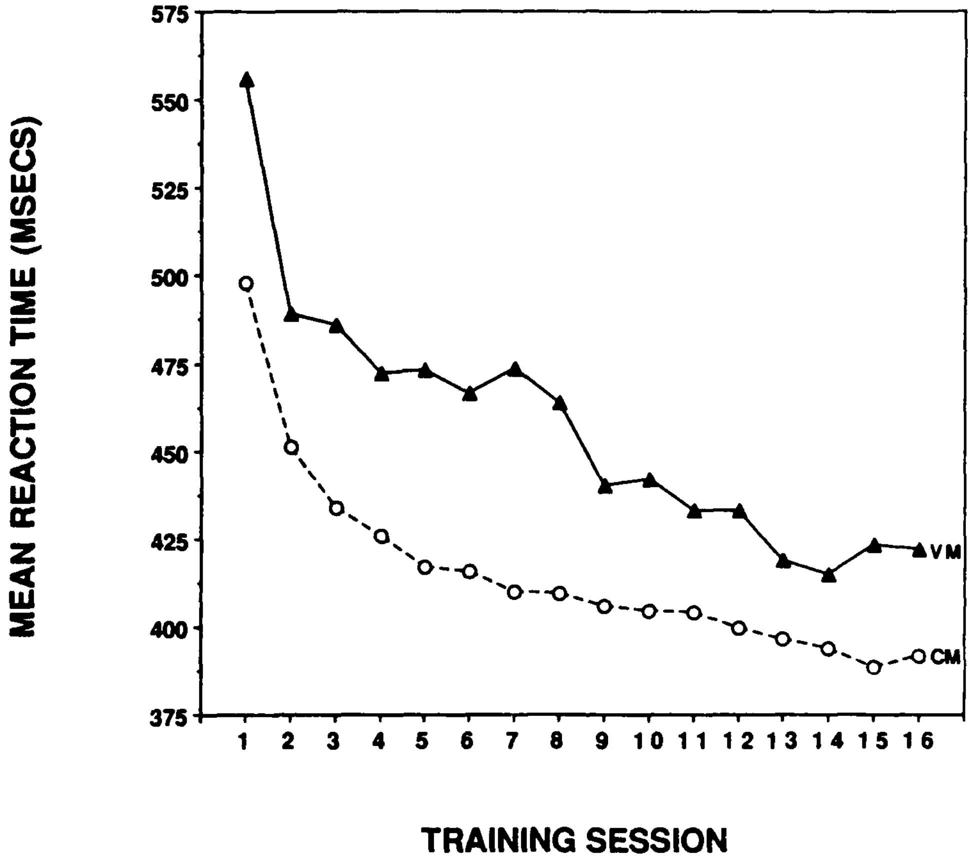


Figure 4. Mean Reaction Time as a Function of Mapping Condition and Training Session - Experiment 2.

based on correct responses. As depicted in the figure, both CM/VM condition and sessions had a substantial effect on reaction time. Reaction times were consistently lower in the CM group than in the VM group, but improved as a function of training in both groups.

A 2 x 4 x 16 Analysis of Variance (ANOVA) was performed on the reaction time data in order to analyze the effects of mapping condition (CM versus VM), memory set size (1-4), and training session (1-16). Mapping condition was a between-subjects variable in this analysis, whereas memory set size and training session were within-subjects variables. This analysis indicated that the main effects of mapping condition [$F(1,30) = 10.12$, $p < .004$], memory set size [$F(3,90) = 653.76$, $p < .001$], and training sessions [$F(15,450) = 48.35$, $p < .001$] were significant. In addition, the analysis showed that the interaction of CM/VM and memory set [$F(3,90) = 94.79$, $p < .001$], and the interaction of memory set and session [$F(45,1350) = 7.28$, $p < .001$] were also significant. All other interactions were not reliable.

As in Experiment 1 with spatial pattern information, the main effect of CM/VM mapping condition is consistent with the development of some degree of automatic processing in the CM condition, in that reliably faster responses were exhibited in this condition as compared with the VM condition. The significant improvement in performance with training and the effect of memory set size on reaction time are also consistent with Experiment 1 and with previous memory search work using different verbal materials (e.g., Fisk & Schneider, 1983; Hale, 1988). Therefore, the main effects are consistent with previous results, and support the development of automatic processing in the CM group with the letter sequence materials that were used.

In addition to reaction time differences between the CM and VM groups, a second criterion applied in Experiment 1 to assess the development of automatic processing was a greater reduction in the effect of task demand within the CM group versus the VM group. The same criterion was also applied in the present experiment, and Figure 5 shows the effect of memory set size on reaction time in the CM and VM groups for both the first and last sessions of training. As is clear from the figure, memory set size had a substantial effect on both CM and VM performance during the first training session. At the conclusion of training, however, the effect of memory set on reaction time had been markedly attenuated in the CM group, while set size continued to show a strong effect on VM group performance.

In order to characterize the effects of reductions in memory set size on performance in each group, slopes of the functions depicted in Figure 5 were computed. Within the CM group, the slope of the Session 1 function was 35.95 ms, while the slope of the Session 16 function was 17.63 ms. In the VM group, however, the slope of the Session 1 function was 64.09 ms, and was reduced to 43.72 ms by Session 16. Therefore, the CM group showed a 51% reduction in slope with training as compared to a 32% reduction in slope in the VM group. Once again, this type of CM-VM difference is consistent with the development of automatic processing in the CM group.

Accuracy of Responding. Figure 6 shows mean percent correct responses as a function of CM/VM group and training

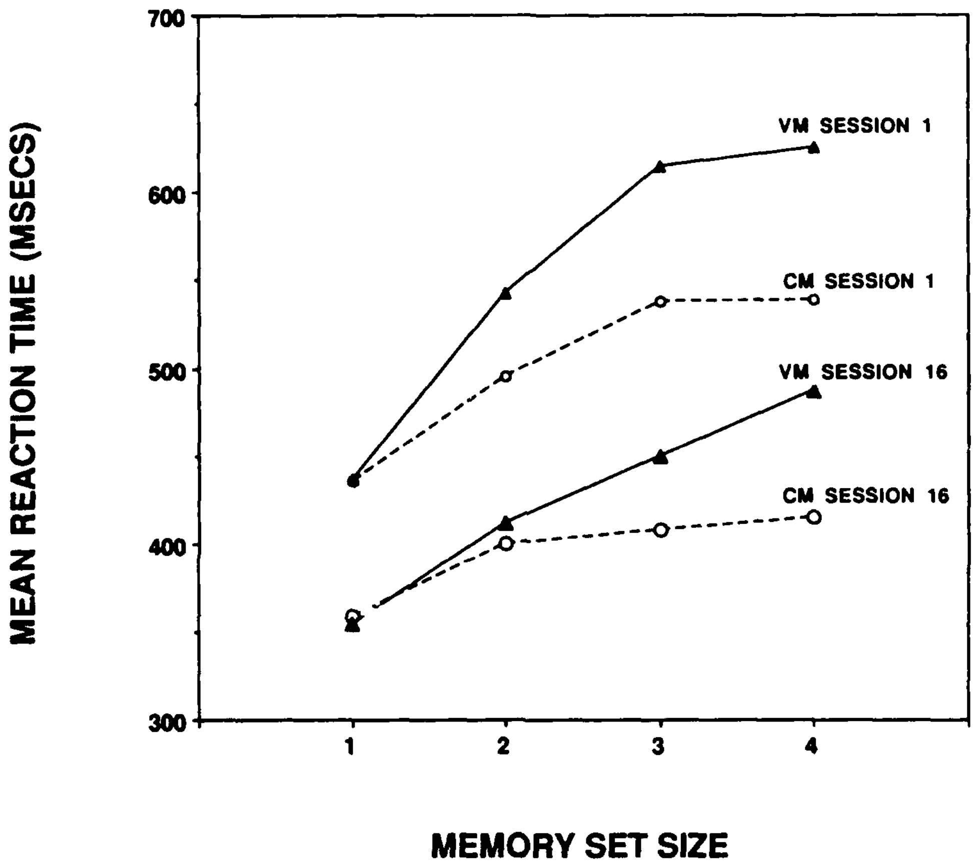


Figure 5. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training Session - Experiment 2.

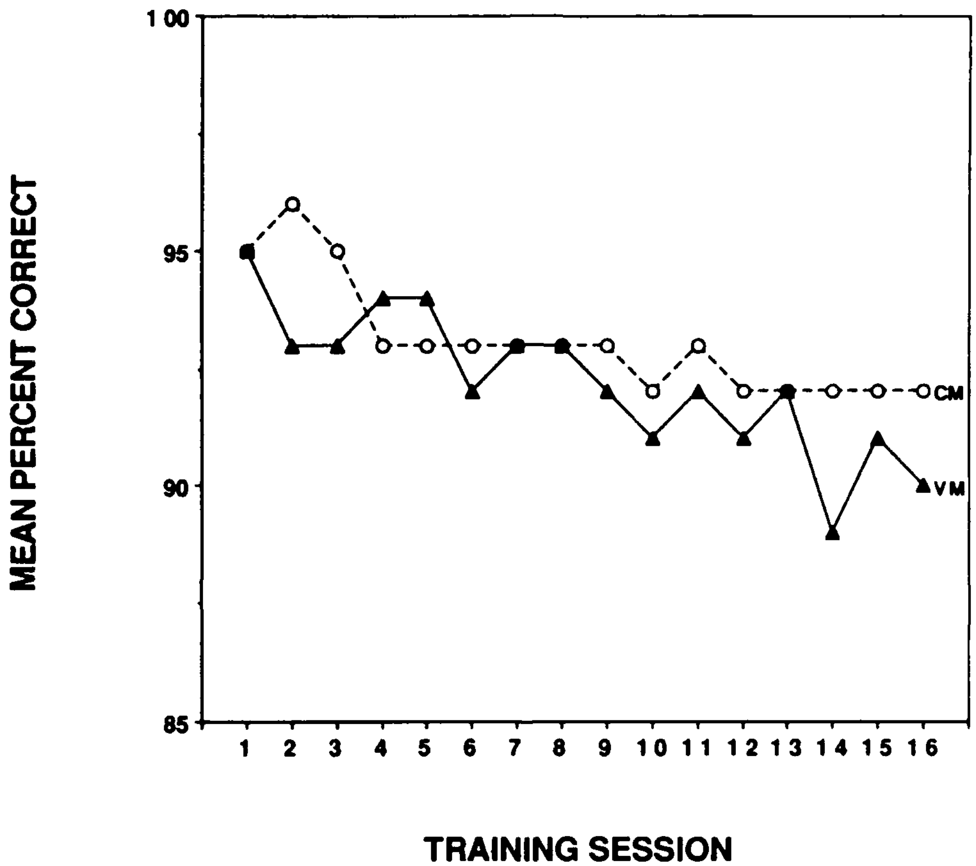


Figure 6. Mean Percent Correct as a Function of Mapping Condition and Training Session - Experiment 2.

session. As is clear from the figure, response accuracy was consistently high and approximated the 90% criterion level that had been required of the subjects.

A 2 x 4 x 16 ANOVA which was comparable to that performed on the reaction time data was conducted on the percent correct responses. This analysis demonstrated no main effect of mapping condition [$F(1,30) = 1.91$, $p > .17$]; a significant main effect of memory set size [$F(3,90) = 51.15$, $p < .001$]; and a reliable effect of training sessions [$F(15,450) = 8.99$, $p < .001$]. The CM/VM x memory set interaction [$F(3,90) = 2.68$, $p < .052$] was marginally significant, as was the CM/VM x session interaction [$F(15,450) = 1.54$, $p < .09$]; and the CM/VM x memory set x session interaction [$F(45,1350) = 1.30$, $p < .09$]. The main effect of memory set size reflects increased error rates in both groups as memory set size increased, and the main effect of training session indicates that the trend for decreased accuracy in both mapping groups which is apparent in Figure 6 is significant. The failure to find significant CM versus VM differences indicates that the difference in reaction times noted in Figure 4 cannot be attributed to a significant speed-accuracy tradeoff. This result therefore supports the interpretation of reaction time differences as consistent with the development of automatic processing in the CM group.

Experiment 3
Development of Automatic Processing in a Task Requiring the Processing of Complex Alphanumeric Information With Similar Target and Distractor Sets

Purpose

The results of Experiment 2 demonstrated performance levels, with letter sequence sets, that were consistent with the development of automatic processing of this type of material in the CM condition. An important issue which was not addressed by Experiment 2 but which is relevant to acquisition of automatic processing by operators of Air Force systems concerns the similarity or discriminability of the target and distractor sequence sets. As noted above, the sequences used in Experiment 2 were designed to be highly discriminable in order to minimize possible confusions between target and distractor sets. However, such high discriminability cannot be assured in real-world systems, where the possibility exists that target and distractor sequences could be highly similar.

Eberts and Schneider (1986), in their work with spatial patterns, suggested that the relative lack of discriminability between targets and distractors was a possible factor in the failure to demonstrate evidence of full automatic processing in that series of experiments. Any effect of target/distractor discriminability on the development of automatic processing would have important implications for applications to Air Force systems. Therefore, Experiment 3 was conducted to investigate the effect of similar target and distractor sets on performance of subjects under a CM condition. The same type of memory search task that had been employed in Experiment 2 was used in the present experiment.

Method

Subjects. Subjects were 16 University of Dayton students. They were paid $4.00 per hour for their participation. In addition to this base rate of pay, subjects were awarded a bonus payment of $1.00 per hour for appearing on time for each scheduled experimental session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer was programmed to present stimuli, control the timing of stimulus presentation, and collect subject responses. Subjects viewed spatial pattern stimuli on a Zenith ZCM-1490 high-resolution color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance levels was presented to subjects through Realistic Nova-16 headphones.

Procedure. Subjects performed a version of the Sternberg (1966) memory search task. At the beginning of each trial, subjects were shown a memory set of one to four items on the computer CRT screen. These letter sequences remained on the screen until the subject pressed a designated key on the computer. At this point, a 4.5-mm-high and 4.3-mm-wide fixation cross was presented in the middle of the screen for 500 ms. The fixation cross was replaced by a single test item, which was displayed for a maximum of 2 seconds or until the subject responded.

The subject was instructed to decide if the test item was a member of the memory set. Subjects responded "yes" or "no" by pressing with their preferred hand a labeled response button on the keyboard. One-half of the target items in each block of trials were members of the memory set; the other sequences were not. Both reaction time and response accuracy data were collected. Each subject was encouraged to respond rapidly while maintaining an accuracy level of 90% or higher within each session.

At the completion of each trial, visual and auditory feedback were provided. Incorrect responses were followed by a "Wrong Response" message on a red background, and a tone. A correct response was followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence if the reaction time was less than 400 ms.

Additional feedback was provided at the completion of each session. This feedback included mean reaction time and accuracy performance levels from each of the previous training sessions. Subjects were also given information that permitted them to determine which of four levels of proficiency had been achieved during each session. As in the previous experiment, the levels were "Novice," "Professional," "Expert," and "Ace." Each level was based on reaction time performance, with "Novice" representing the least proficient level and "Ace" the most proficient level of performance.

Each subject participated on each of 4 days. On each day, subjects completed four training sessions, which consisted of 10 blocks of 20 trials each. Consequently, there were 800 training trials each day and a total of 3,200 training trials during the entire experiment.

Stimulus Materials. Each sequence was composed of three letters, and was intended to represent the same type of complex alphanumeric information as that investigated in Experiment 2. However, in this instance, the discriminability of target and distractor sets was reduced in order to assess the impact of target/distractor confusability on levels of CM performance.

The same two sets of four sequences which served as targets during Experiment 2 also served as targets during this experiment. As noted previously, these had been chosen from the 50% association value listings in the Underwood and Schultz (1960) norms. In order to reduce the discriminability of target and distractor sets for this experiment, new distractor sets were generated through permutation of the letter combinations in the target sets. This permutation was such that some sequences in the target and distractor sets shared letters in each of the three ordinal positions within the sequence, thereby requiring subjects to attend to the entire sequence in order to reliably distinguish target from distractor sets. These sets of sequences were therefore chosen to maximize similarity and any potential confusability between target and distractor items. Examples of the letter sequences used in this experiment are shown in Appendix C.

Design. Two independent variables were manipulated: (a) memory set size, and (b) training sessions. One set of items served as targets throughout training for an individual subject, and a second set served as distractor patterns. The two sets of target sequences and the two sets of distractor sequences were distributed such that each set served an equal number of times as targets and distractors, respectively. One-half of the subjects received sequences in uppercase letters; the other half received sequences in lowercase letters. Memory set size was manipulated within blocks of trials in each group, and consisted of one to four items. Subjects completed a total of 16 sessions of practice trials during training.

Results

Reaction Time. Mean reaction time to stimuli as a function of training sessions is illustrated in Figure 7. The means presented in Figure 7 are based on correct responses. As depicted in the figure, training led to substantial reductions in reaction time across sessions.

A 4 x 16 Analysis of Variance (ANOVA) was performed on the reaction time data in order to analyze the effects of memory set size (1-4) and training session (1-16). Both variables represented within-subjects effects. This analysis showed that the main effects of memory set size [$F(3,45) = 366.36$, $p < .001$] and training sessions [$F(15,225) = 26.25$, $p < .001$] were significant. The analysis also demonstrated that the interaction of memory set and session [$F(45,675) = 11.84$, $p < .001$] was also significant.

In order to further investigate the significant memory set x session interaction, mean reaction time as a function of memory set was computed for the first and last sessions of training. Based on the results of the previous experiment, it was expected that the slope of the function

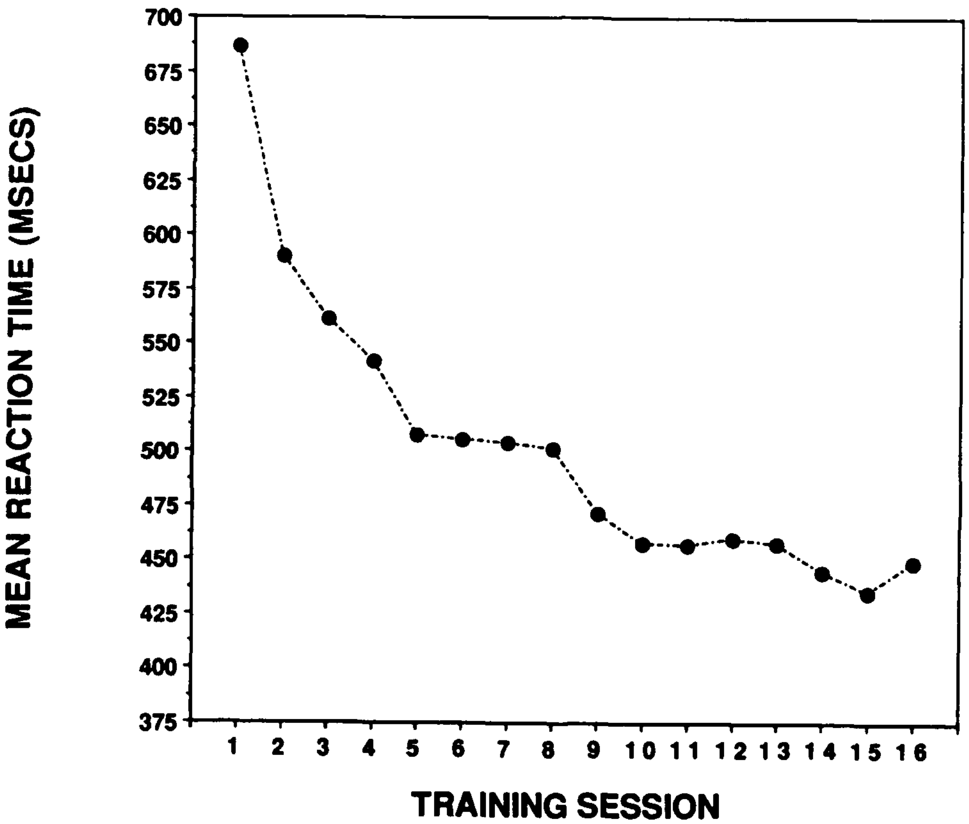


Figure 7. Mean Reaction Time as a Function of Training Session - Experiment 3.

relating reaction time to memory set size would be reduced in the last session of training relative to the first session of training. Figure 8 shows mean reaction time as a function of memory set size and training session, and indicates that the effect of memory set size on reaction time was attenuated across the course of training. The slope of the function relating reaction time to memory set size was 93.02 ms during the first training session, and was reduced to 39.10 ms during the last training session. This represents a 58% reduction in the slope across training, and compares favorably with the 51% reduction that was obtained in the CM condition in Experiment 2. These results are therefore consistent with the development of automaticity with the similar sets used in this experiment.

Accuracy of Responding. Figure 9 shows mean percent correct responses as a function of training session. As is clear from the figure, response accuracy was consistently high and generally exceeded the 90% criterion level required of the subjects.

A 4 x 16 ANOVA which was comparable to that performed on the reaction time data was conducted on the percent correct responses. This analysis demonstrated a significant main effect of memory set size [$F(3,45) = 37.25$, $p < .001$] and a reliable effect of training sessions [$F(15,225) = 4.77$, $p < .001$]. The interaction of memory set size and training session also proved to be significant [$F(45,675) = 1.83$, $p < .002$]. The main effect of memory set size reflects increased error rates as memory set size increased, and the main effect of training session reflects significant variation in response accuracy across training. As indicated in Figure 9, accuracy of responding showed an improvement in

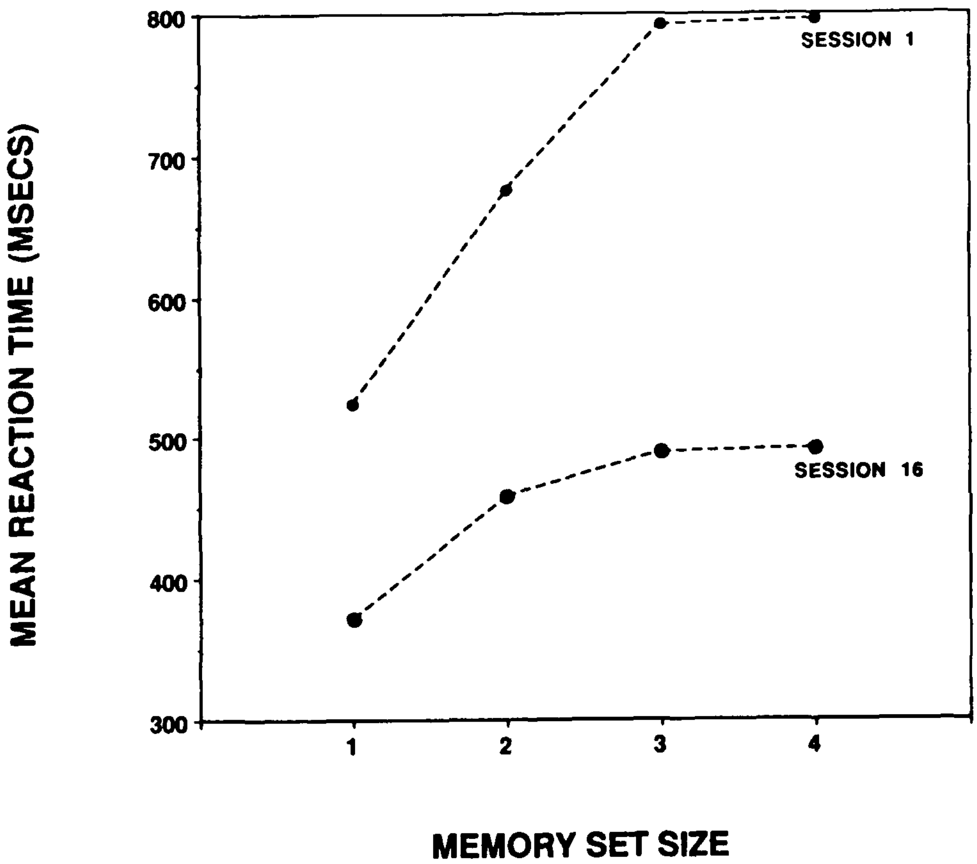


Figure 8. Mean Reaction Time as a Function of Memory Set Size and Training Session - Experiment 3.

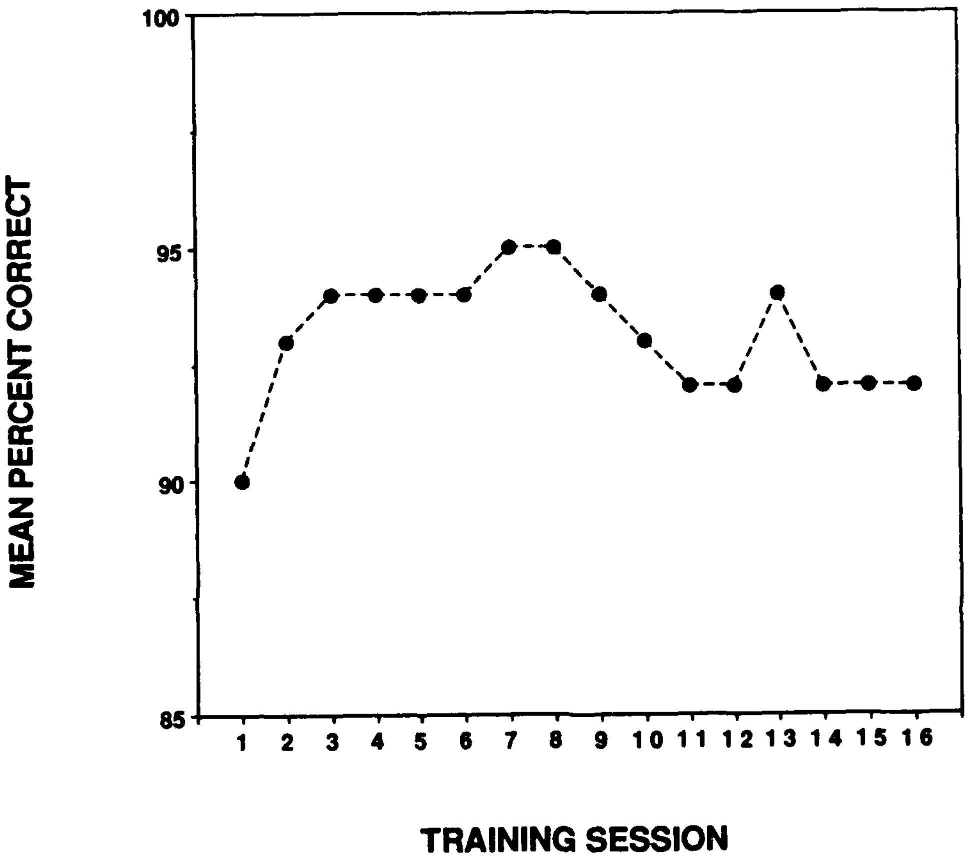


Figure 9. Mean Percent Correct as a Function of Training Session - Experiment 3.

the last session of training as compared to the first session.

Comparison of Similar and Dissimilar Target/Distractor Set Conditions

Comparison of the results of Experiments 2 and 3 permits some assessment of the impact of target/distractor discriminability on the development of automatic processing in CM conditions. Figure 10 shows mean reaction time as a function of training session and target/distractor similarity/dissimilarity from the two experiments.

As is clear from the figure, target/distractor discriminability had a substantial effect on performance levels in the two CM conditions, with reaction times in the dissimilar CM condition demonstrating a consistent advantage over those in the similar condition over training sessions.

In order to investigate the impact of target/distractor similarity on performance in the CM conditions, a 2 x 4 x 16 ANOVA was performed to assess the effect of CM condition (similar versus dissimilar target/distractor sets), memory set size (1-4), and training session (1-16). This analysis confirmed the trends noted above, and indicated that the main effect of CM condition [$F(1,31) = 36.5$, $p < .001$] was significant, as were the main effects of memory set size [$F(3,93) = 502.89$, $p < .001$] and training session [$F(15,465) = 45.74$, $p < .001$]. The analysis also indicated the significance of the CM condition x memory set interaction [$F(3,93) = 94.01$, $p < .001$], the CM condition x training session interaction [$F(15,465) = 45.74$, $p < .001$], the memory set x training session interaction [$F(45,1395) = 14.98$, p

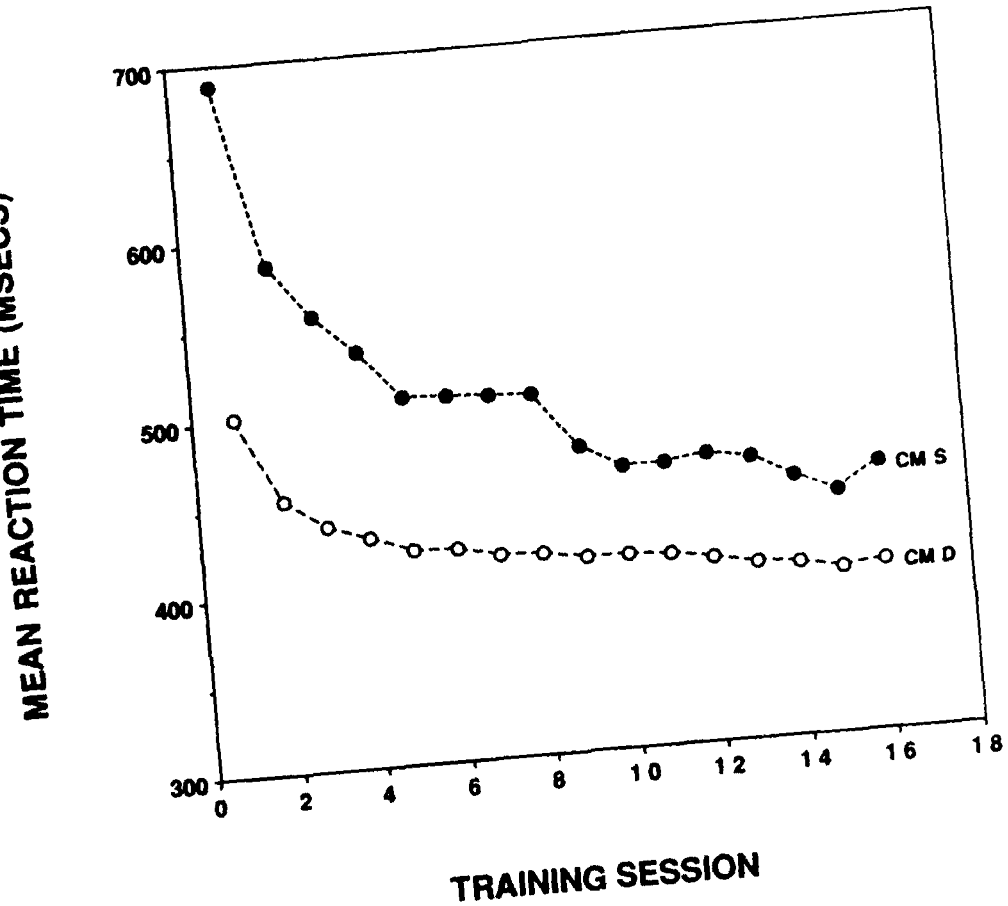


Figure 10. Mean Reaction Time as a Function of CM Condition and Training Session - Experiment 2 (Dissimilar) versus Experiment 3 (Similar).

$<.001$], and the CM condition x memory set x training session interaction [$F(45,1395) = 4.20$, $p < .001$].

The data presented in Figure 10 indicate that the CM similar group failed to achieve mean reaction times that were as low as those achieved in the CM dissimilar group. In addition to reaction time differences, an index of the degree of automaticity discussed above is the effect of memory set variations on performance at the conclusion of training. Figure 11 shows mean reaction time as a function of memory set size for the first and last training sessions in the CM similar and the CM dissimilar conditions. As is clear from the figure, the CM dissimilar condition showed a substantially reduced effect of memory load on performance relative to the CM similar condition at the completion of training.

General Discussion

The results of Experiments 1, 2, and 3 support the capability of subjects to develop some degree of automatic processing in tasks which involve the processing of spatial and alphanumeric information of the type required in Air Force C2 systems.

Experiment 1 demonstrated differences in CM and VM performance that were consistent with the development of automaticity in the CM condition. Mean reaction time in the CM condition was consistently lower than in the VM condition, and CM performance was less affected by memory load than VM performance at the conclusion of training. Eberts and Schneider (1986), in their work with detection of complex spatial patterns, also reported significant CM and

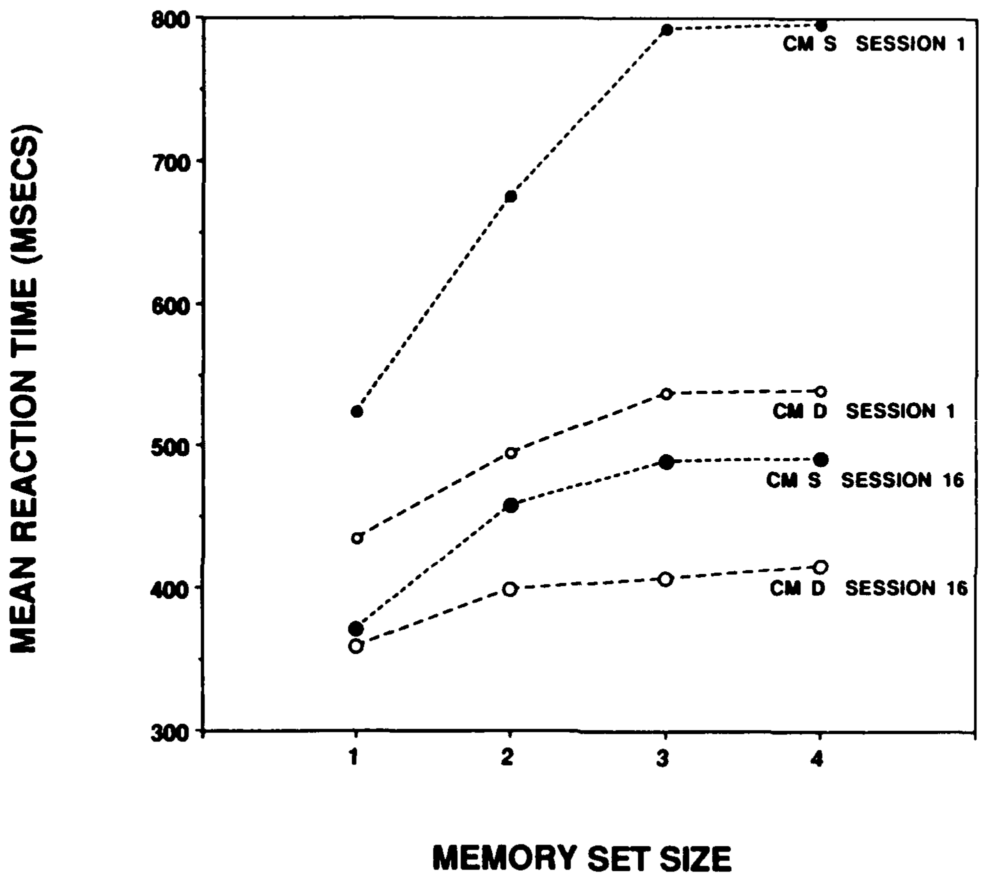


Figure 11. Mean Reaction Time as a Function of CM Condition and Memory Set Size in the First and Last Training Sessions - Experiment 2 (Dissimilar) versus Experiment 3 (Similar).

VM differences in the number of patterns which were successfully detected. The results of Experiment 1 and the Eberts and Schneider work are therefore consistent with respect to these differences.

Eberts and Schneider (1986), however, also reported approximately equal decrements in the CM and VM conditions as task demand was manipulated by increasing the number of display channels that were to be searched for target patterns. This result differs from that obtained in Experiment 1 in which CM performance at the conclusion of training was relatively unaffected by increases in memory set size as compared with VM performance. It should be noted that the task demand manipulations in Experiment 1 and those of Eberts and Schneider are different, and that display load manipulations of the type employed by Eberts and Schneider may not be equivalent to the memory load manipulation used here. Nonetheless, the present results do demonstrate the relative invariance in performance with increased processing load that is characteristic of automatic processing.

In addition to task demand manipulation differences, there are other potentially important differences between Experiment 1 and the Eberts and Schneider work which bear on applications to Air Force systems and which should be investigated in future research. For example, the patterns used by Eberts and Schneider were composed of successively presented oriented line segments. Recognition of a pattern therefore required subjects to retain and integrate several line segments. It therefore appears that this integration requirement imposed demands on short-term memory that were not present in the current experiment. The oriented line segment patterns used by Eberts and Schneider were also possibly more complex and potentially less discriminable than those used in the present experiment. Although patterns used in Experiment 1 were composed of five circular elements rather than the three line segments in the previous work, there was no orientation component to the current patterns, and this may have resulted in less complexity for subjects than in the Eberts and Schneider research. In addition, target and distractor sets in the current experiment were developed to be representative of different classes of target movement (e.g., acceleration, deceleration) and should therefore have been highly discriminable. As noted above, Eberts and Schneider suggested that failure to achieve strong evidence of automatic processing in their experiments may have been related to difficulties in discriminating target and distractor stimuli in their experiment. The results of Experiments 2 and 3 in the current series support the importance of target/distractor discriminability with alphanumeric materials, and this issue should therefore be further investigated with the spatial pattern materials used in Experiment 1. Discriminability among the spatial patterns used in that experiment could be reduced by mixing the types of movement represented by patterns across target and distractor sets.

Additional important areas for work with spatial patterns include investigation of the effects of increased pattern complexity in the form of dynamic movement of target elements, and with the requirement to process orientation information. For example, dynamic movement of target elements to simulate the growth of targets on a system display would constitute a higher-fidelity representation of targets found in some Air Force systems, and would represent an intermediate step in pattern integration requirements between the present work and that of Eberts and Schneider (1986).

The results of Experiments 2 and 3 are consistent with the development of some degree of automatic processing in CM conditions using the type of complex alphanumeric information that must be processed by operators of some Air Force systems. Training with sets of both similar and dissimilar target/distractor sets under CM conditions resulted in substantial reductions in the effect of memory load on reaction time performance. This type of result has been demonstrated by other investigators (e.g., Fisk & Schneider, 1983; Hale, 1988) using other types of verbal information (e.g., semantic), and is consistent with the development of automatic processing in the present CM conditions.

Although there is evidence to support the development of automatic processing in both CM conditions, it is clear that the levels of performance achieved under the CM/Dissimilar (CM-D) condition exceeded those that were achieved with the same target sequence sets under equivalent amounts of training in the CM/Similar (CM-S) condition. This is not only true of overall reaction time, but is also reflected in the greater effect of memory load on performance in the CM-S condition at the conclusion of training. Therefore, it appears that lack of discriminability between target and distractor sets appreciably slowed the development of automatic processing with these materials. As noted above, this lack of discriminability was a possible factor cited by Eberts and Schneider in discussing their failure to find evidence of full automaticity with complex spatial patterns. The present results are consistent with this hypothesis.

If part-task training of actual C2 components exhibits acquisition functions which are similar to those demonstrated here, the amount of training required to attain some degree of automatic processing would appear reasonable for application to Air Force training programs. Total training trials across the three experiments ranged from 3,200 to 4,000 trials. Although extensive, this amount of training was provided in 8 to 10 hours. This level of training effort would appear to be quite feasible for part-task training of CM components during the course of a C2 training program.

With the current results as a baseline for complex alphanumeric material, future work should examine more complex decision tasks which involve the conjunction of sequences and numerical values. Operators of some Air Force systems, for instance, are required to rapidly scan a set of sequences and associated numerical values in order to determine if any of the values are beyond specified tolerance limits for the system parameter represented by the sequence. The values associated with particular system parameters are consistent; thus, some degree of automatic processing of the display/memory search component of this task should be possible with training. In effect, the consistency represented in this task represents a higher-order or rule-based consistency, as opposed to the type of stimulus-response consistency that was investigated in the current experiments. A number of investigators (e.g., Fisk, Oransky, & Skedsvold, 1988; Kramer, Strayer, & Buckley, 1989) have recently demonstrated application of rule-based consistencies to the development of automatic processing with different materials, and this type of research should be extended to the type of alphanumeric materials discussed above.

III. TRANSFER OF AUTOMATIC PROCESSES IN TASKS REQUIRING THE PROCESSING OF COMPLEX ALPHANUMERIC INFORMATION

Another major issue pertaining to the application of automatic processing principles to complex skill acquisition in Air Force C2 systems concerns the transfer of automaticity that can be expected with the types of materials described above. Data concerning the conditions and limits of automatic component transfer with such materials are very important for the design of training programs intended to support the development of these components. Investigations of the effect on transfer of factors such as conditions of original training and degree of similarity between the original and transfer materials are critical to eventual applications of automaticity to skill development within Air Force training programs.

A number of recent experiments (e.g., Hale, 1988; Hassoun & Eggemeier, 1988; Schneider & Fisk, 1984) have demonstrated transfer of automatic processing with semantic materials that are important to operator performance in complex systems. Hale (1988), for instance, investigated transfer of automatic processing to unpracticed exemplars of previously trained semantic categories in a category memory search paradigm. The paradigm used by Hale was similar to the search paradigm used in Experiments 1 through 3. In the Hale (1988) research, the memory set (m-set) consisted of semantic category labels (e.g., "Vehicles," "Countries"), and subjects indicated whether or not a subsequently presented item (e.g., "Airplane") was an exemplar of an m-set category. After extensive CM training with a set of category exemplars, subjects were transferred to one of three semantic search conditions: (a) Same Semantic Categories/Same Exemplars (S/S), (b) Same Semantic Categories/Different Exemplars (S/D), or (c) Different Semantic Categories/Different Exemplars (D/D). At transfer, the S/D group demonstrated significantly faster reaction times than those of the D/D group but slower reaction times than those of the S/S group, suggesting transfer to the new exemplars of the trained semantic categories.

Similar results were reported by Schneider and Fisk (1984) in another variant of a category search paradigm, and by Hassoun and Eggemeier (1988) in a word search paradigm under high memory load conditions. The results of these experiments are important, because they demonstrate positive transfer of automatic processing with a class of materials that must be processed by operators of C2 systems.

A second important transfer issue which was investigated by Hale (1988) concerned the effect of changes in the physical characteristics of the material that was to be processed on transfer. One-half of the subjects in each of the semantic transfer groups outlined above experienced a letter case switch at transfer, whereas the remaining subjects in each group did not. The purpose of this letter case switch was to assess the relative importance of physical versus semantic changes in the semantic search paradigm. The results indicated that semantic changes were more important than physical changes, but also indicated that there was a significant effect of physical change on transfer performance.

Such physical changes are particularly important to training applications, in that training devices do not always present material in exactly the same physical appearance as the actual system, and because presentation of information is not always identical across system displays. If automatic component processes are markedly affected by physical changes in the format of the information which is to be processed, this would have very important implications for the development of training devices to support the acquisition of such components.

Although there have been several investigations of semantic transfer in the recent automatic processing literature, issues pertaining to transfer of the type of complex alphanumeric materials used in Experiments 2 and 3 above have not been researched. Therefore, a series of three experiments was conducted to investigate the influence of physical characteristics on transfer of such materials.

Experiments 4 and 5 examined transfer of complex alphanumeric materials with dissimilar target/distractor sets under VM and CM conditions, respectively. Experiment 6 investigated transfer under CM conditions with similar target/distractor sets.

Experiment 4
Transfer of VM Training with Complex Alphanumeric Materials with Dissimilar Target/Distractor Sets

Purpose

The purpose of this experiment was to investigate transfer with dissimilar target/distractor sets in the VM memory search task that had been trained in Experiment 2. The three transfer conditions included: (a) a change in the physical characteristics of the letter sequences that were to be processed, (b) a change in the letter sequences themselves, and (c) changes in both the physical characteristics and the letter sequences. A control condition in which no changes occurred was also included. Physical changes were introduced by manipulating the letter case of the sequences that were to be processed by subjects. In those conditions which involved a letter case switch at transfer, all sequences including those in the memory set and probe test items were presented in the new case.

As noted above, Hale (1988) had investigated the influence of such letter case manipulations on performance of a semantic category search task, and had reported relatively small effects of this variable versus changes in the semantic information in that type of task. However, the category search task used by Hale required processing items at the semantic level. It therefore appeared possible that processing letter sequences with relatively low meaningfulness in a search task which did not require semantic category processing might be more heavily dependent upon the physical characteristics of the letters which made up the sequences. If processing of letter sequences is heavily dependent upon such physical characteristics, a case switch might have more substantial effects on this type of alphanumeric material than with the semantic materials used by Hale. Lane and Kleiss (1985), for example, had reported significant levels of performance disruption following a letter case switch in a CM memory/display search task which required that subjects process individual letters of the alphabet.

Due to the fact that it dealt with transfer under VM training conditions, the present experiment was conducted principally as a control condition for Experiment 5, which investigated the same transfer issues under CM training conditions.

Method

Subjects. Subjects were the same 16 University of Dayton students who had participated in the VM condition in Experiment 2. They were paid $5.00 per hour for their participation.

Apparatus. The experiment used the same type of Zenith Data Systems 248 computer and Zenith ZCM-1490 high-resolution color monitor that was used in Experiment 2. Responses were made on same arrow keys of a standard expanded IBM-compatible keyboard that were used previously. Auditory feedback concerning performance levels was once again presented to subjects through Realistic Nova-16 headphones.

Procedure. Subjects performed the same type of memory search task which had been performed in Experiment 2. The same VM target/distractor mapping used with these subjects in Experiment 2 was used throughout this experiment. On each trial, subjects were presented with a memory set of four items which remained on the CRT screen until the subject pressed a designated key. A fixation cross then appeared in the middle of the screen for 500 ms, and was replaced by a single test item, which was displayed for a maximum of 2 seconds or until the subject responded.

Subjects determined if the test sequence was a member of the memory set, and responded "yes" or "no" by pressing a labeled response button on the keyboard. One-half of the target sequences in each block of trials were members of the memory set. Both reaction time and accuracy measures were collected. The same 90% criterion level used in Experiment 2 was maintained in this experiment.

Visual and auditory feedback in the same format as that in Experiment 2 was provided to subjects at the completion of each trial. An incorrect response was followed by a "Wrong Response" message on a red background, and a tone. Correct responses were followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence for reaction times under 400 ms.

Summary feedback which included mean reaction time and percent correct responses was also provided at the completion of each session. The same four proficiency levels presented during Experiment 2 were used.

The experiment was divided into two phases: (a) pre-transfer and (b) transfer. The purpose of the pre-transfer phase was to establish a performance baseline that could be used to assess levels of transfer in the subsequent phase, and to provide practice to the subjects in performance of the search task only under the memory set size four condition. Memory set size four was used in this experiment in order to increase the potential to detect any transfer differences which might be present.

Subjects completed two sessions of pre-transfer performance on the day following the completion of Experiment 2. Each pre-transfer session included 10 blocks of 20 trials each, for a total of 400 pre-transfer trials. Memory set size was held constant at four items. Pre-transfer sessions used the same target and distractor sequence sets and the same letter case that had been used to train the particular subject in Experiment 2. Four subjects therefore continued with dissimilar target/distractor set 1 presented in uppercase letters (D1-U); four subjects, with dissimilar target/distractor set 1 in lowercase letters (D1-L); four subjects, with dissimilar target/distractor set 2 in uppercase letters (D2-U); and four subjects, with dissimilar target/distractor set 2 presented in lowercase letters (D2-L).

After completion of pre-transfer, all subjects were transferred to one of four conditions: (a) Change/Change (C/C), (b) No Change/Change (NC/C), (c) Change/No Change (C/NC), or (d) No Change/No Change (NC/NC). The first letter group designation indicates if the letter case of the transfer materials was different from pre-transfer, and the second designation indicates if the transfer sequences represented a change from pre-transfer. Because of changes which occurred in the letters that made up the sequences, all conditions which involved a manipulation of the content of the sequences also involved a change in the physical features of the letters that were to be processed. Therefore, although the C/NC group represented a pure change in the physical characteristics of the information to be processed, the NC/C and C/C groups also involved some changes in the physical features of the sequences. The latter group included the physical feature changes associated with both the sequence changes and the letter case switch. There were four subjects assigned to each transfer group, and each transfer group included a representative of each combination of letter sequence set and letter case condition (i.e., D1-U, D1-L, D2-U, D2-L). Examples of the types of letter sequences used in each transfer condition are included in Appendix D.

The transfer phase for all subjects consisted of 10 blocks of 20 trials each, for a total of 200 trials.

Design. Two independent variables were included in the design: (a) blocks of pre-transfer or transfer trials, and (b) transfer group (C/C, NC/C, C/NC, NC/NC).

Results

Pre-Transfer

Pre-transfer and transfer data were analyzed separately. In each case, correct responses in blocks of 20 trials were used in the data analyses.

Figure 12 shows mean reaction time as a function of transfer group across blocks of 20 pre-transfer trials. As is shown in the figure, transfer group did not have a major effect on mean response time but there was a trend for increases in reaction time with practice. A 4 x 10 ANOVA was conducted on these data in order to investigate the effects of transfer group (C/C, C/NC, NC/C, and NC/NC) and pre-transfer blocks on reaction time performance. This analysis indicated that neither the main effect of transfer group [$F(3,12) = 0.24$, $p > .85$] nor the interaction of transfer group and blocks [$F(27,108) = 0.84$, $p > .65$] was significant. The main effect of pre-transfer blocks [$F(9,108) = 7.46$, $p < .001$] was, however, reliable. The latter effect indicates that the trend toward increased reaction times noted above was significant.

Although it was anticipated that VM performance would be highly variable and would not show marked improvements in performance with practice, there is no apparent reason for the noted trend. One potential factor which may have contributed to the trend is subject motivation. It is possible, for instance, that the inability of subjects to attain reaction times that were the same as the pre-transfer baselines achieved in Experiment 2 could have contributed to a drop in subject motivation. Mean reaction times reported to subjects in Experiment 2 reflected the average levels of performance on memory set sizes 1-4. In the VM condition, these times would be expected to be considerably lower than the reaction times associated with the memory set size 4 condition in the current experiment. This increase over previous baselines may have had an adverse effect on subject motivation in all VM groups.

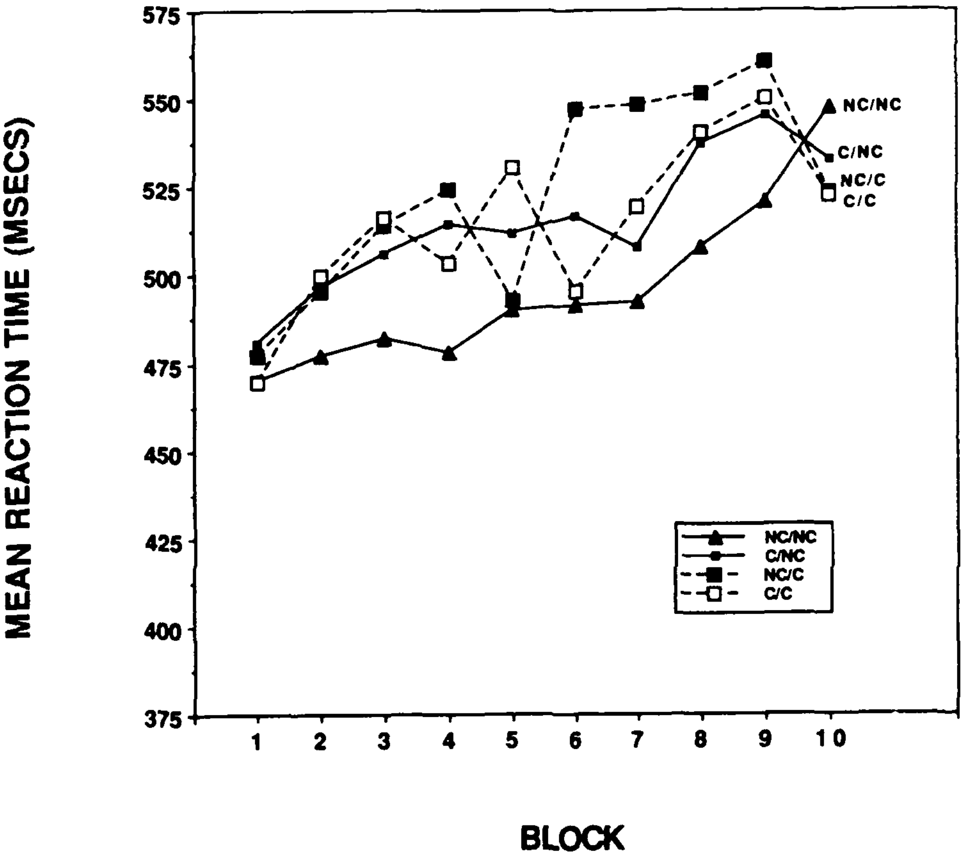


Figure 12. Pre-Transfer Mean Reaction Time as a Function of Transfer Group and Blocks - Experiment 4.

Figure 13 shows mean percent correct as a function of transfer group across blocks of pre-transfer trials. As illustrated in the figure, neither transfer group nor pre-transfer blocks had an appreciable effect on accuracy. A 4 x 10 ANOVA was performed on these data to examine the effects of transfer group (C/C, C/NC, NC/C, and NC/NC) and pre-transfer blocks on the accuracy of performance. The main effect of transfer group [$F(3,12) = 0.50$, $p > .65$], the main effect of blocks [$F(9,108) = 1.35$, $p > .20$], and the transfer group x block interaction [$F(27,108) = 1.01$, $p > .45$] were all nonsignificant.

The absence of any significant effect involving transfer groups in both analyses indicates that there were no significant differences in performance between the groups at the conclusion of training, thereby facilitating interpretation of any transfer differences.

Transfer

Difference scores for use in transfer analyses were computed by subtracting each subject's mean reaction time (RT) for the last pre-transfer training block from that subject's mean RT for each transfer block. These difference scores are illustrated in Figure 14. As can be seen in the figure, transfer group did not have a substantial effect on performance, but performance continued to improve as transfer progressed.

Difference score data were analyzed with a 4 x 10 ANOVA which included transfer group (C/C, NC/C, C/NC, NC/NC) and blocks of transfer trials. This analysis confirmed the major trends in the data that were discussed in conjunction with

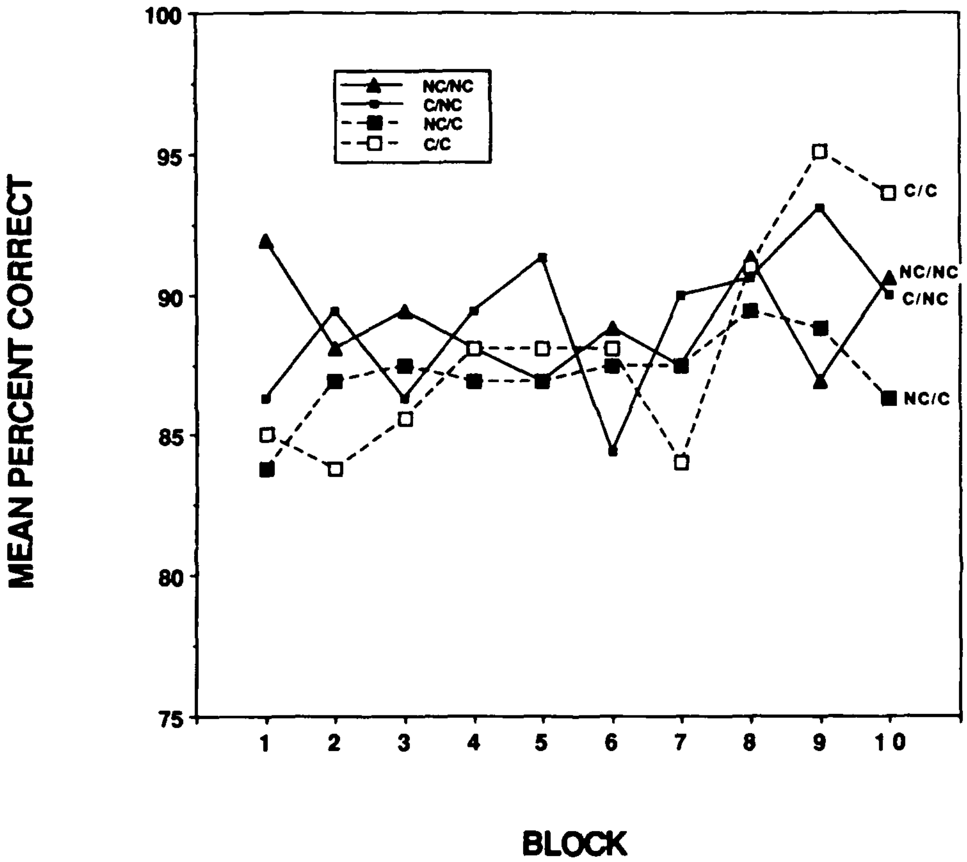


Figure 13. Pre-Transfer Mean Percent Correct as a Function of Transfer Group and Blocks - Experiment 4.

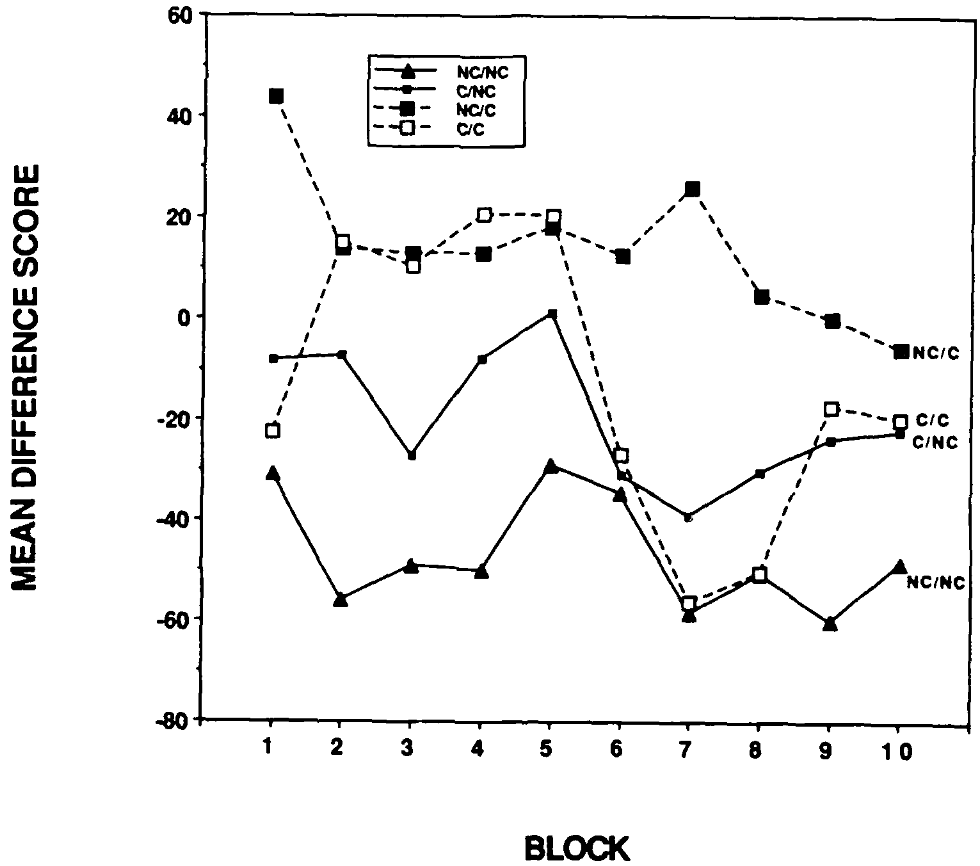


Figure 14. Mean Difference Scores as a Function of Transfer Group and Blocks of Transfer Trials - Experiment 4.

Figure 14. The main effect of transfer group [F(3,12) = 1.53, p >.25] was not reliable, but the main effect of transfer blocks [$F(9,108) = 2.48$, p <.02] was significant. The interaction of transfer group and transfer blocks [$F(27,108) = 1.01$, p >.45] was not significant.

Figure 15 shows mean percent correct as a function of transfer group and blocks of transfer. As was the case with the reaction time data, there was no clear trend for transfer condition to substantially affect performance. A 4 x 10 ANOVA which included transfer group and blocks of transfer trials was performed on the percent correct data. This analysis revealed no main effect of transfer group [$F(3,12) = 0.69$, p >.55], no main effect of transfer blocks [$F(9,108) = 1.37$, p >.20], and no significant group x blocks interaction [$F(27,108) = 0.71$, p >.80].

The failure to find a significant transfer group effect in the VM condition suggests that minimal item-specific information was acquired by subjects during Experiment 2 and during the pre-transfer blocks of trials that preceded transfer. This is not unexpected, because targets and distractors continued to mix roles throughout training, and thus no consistent response to a particular letter sequence was possible. The failure to find strong evidence for item-specific learning at transfer suggests that strategies or similar phenomena may account for a substantial portion of the improvements in performance that were exhibited by subjects in the VM condition during the pre-transfer phase of this experiment and during Experiment 2.

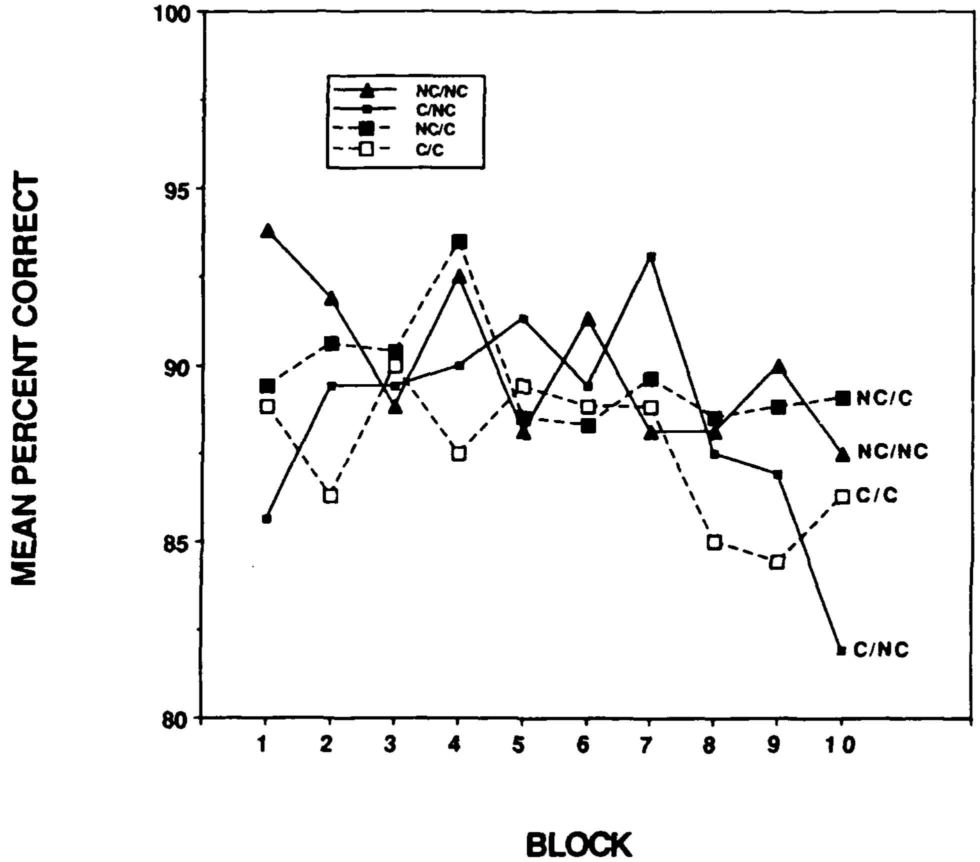


Figure 15. Mean Percent Correct as a Function of Transfer Group and Transfer Blocks - Experiment 4.

Experiment 5
Transfer of CM Training with Complex Alphanumeric Materials with Dissimilar Target/Distractor Sets

Purpose

The purpose of this experiment was to investigate the effect of the same three transfer conditions included in Experiment 4 on performance of a CM memory search task with dissimilar target/distractor sets. The CM memory search task used was the same task that had been trained in Experiment 2. The three transfer conditions included in the current experiment were (a) a change in the physical characteristics of the sequences that were to be processed, (b) a change in the sequences themselves, and (c) changes in both the physical characteristics and the sequences themselves. A control condition in which no changes occurred was once again included. Physical changes were again introduced by manipulating the letter case of the sequences that were to be processed by subjects.

Method

Subjects. Subjects were the same 16 University of Dayton students who had participated in the CM condition of Experiment 2. They were paid $5.00 per hour for their participation.

Apparatus. The experiment used the same type of Zenith Data Systems 248 computer and Zenith ZCM-1490 high-resolution color monitor that had been used in Experiment 2. Responses were made on same arrow keys of a standard expanded IBM-compatible keyboard that were used previously.

Auditory feedback concerning performance levels was once again presented to subjects through Realistic Nova-16 headphones.

Procedure. Subjects performed the same type of memory search task which had been performed in Experiment 2. The same CM target/distractor mapping which had been used with each subject in Experiment 2 was used throughout this experiment. Subjects were presented with a memory set of four items at the beginning of each trial. As in Experiment 2, these items remained on the computer screen until the subject pressed a designated key. This key press was followed by presentation of a fixation cross for 500 ms, and this cross was replaced by a single test item.

Subjects decided if the test item was a member of the memory set, and provided "yes" and "no" responses by pressing labeled buttons on the keyboard. One-half of the target sequences in each block of trials were members of the memory set. Reaction time and response accuracy data were collected. The same 90% criterion level that was used in Experiment 2 was also employed in this experiment.

Visual and auditory feedback was provided to subjects at the completion of each trial, and was identical in format to that used in Experiments 2 and 4. Summary feedback concerning mean reaction time and mean percent correct responses was again provided at the completion of each session. The same four proficiency levels used in Experiment 2 were provided as an additional aid in keeping track of changes in reaction times.

The experiment was divided into two phases: (a) pre-transfer and (b) transfer. The purpose of the pre-transfer phase was to establish a performance baseline that could be used to assess levels of transfer in the subsequent phase, and to provide practice to the subjects in performance of the sequence search task under the memory set size four condition only.

Subjects completed two sessions of pre-transfer performance on the day following the completion of Experiment 2. Each pre-transfer session included 10 blocks of 20 trials, which resulted in a total of 400 pre-transfer trials. Memory set size was held constant at four items. These pre-transfer sessions were performed with the same target and distractor sequence sets in the same letter case that the particular subject had trained on in Experiment 2. Four of the sixteen subjects therefore continued with dissimilar target/distractor set 1 presented in uppercase letters (D1-U); four subjects, with dissimilar target/distractor set 1 presented in lowercase letters (D1-L); four subjects, with dissimilar target/distractor set 2 in uppercase letters (D2-U); and four subjects, with dissimilar target/distractor set 2 presented in lowercase letters 'D2-L).

After completing the pre-transfer phase, subjects were transferred to one of four conditions: (a) Change/Change (C/C), (b) No Change/Change (NC/C), (c) Change/No Change (C/NC), or (d) No Change/No Change (NC/NC). Once again, the first designation refers to whether the letter case of the transfer materials represented a change from the pre-transfer condition, and the second designation indicates whether the transfer sequence set differed from that used in pre-transfer. Because of changes which occurred in the letters which made up the sequences, all conditions which involved a manipulation of the content of the sequences also involved a change in the physical features of the letters that were to be processed. Therefore, although the C/NC group represented a pure change in the physical characteristics of the information to be processed, the NC/C and C/C groups also involved some changes in the physical features of the sequences. The latter group included the physical feature changes associated with both the sequence changes and the letter case switch. Four subjects were assigned to each transfer group, such that each combination of sequence set and letter case (i.e., D1-U, D1-L, D2-U, D2-L) was represented in each group. Examples of the types of letter sequences used in each transfer condition are included in Appendix D.

The transfer phase for all subjects consisted of 10 blocks of 20 trials each, for a total of 200 trials.

Design. Two independent variables were included in the design: (a) blocks of pre-transfer or transfer trials, and (b) transfer group (C/C, NC/C, C/NC, NC/NC).

Results

Pre-Transfer. Pre-transfer and transfer data were analyzed separately. Correct responses in blocks of 20 trials were used in both analyses.

Mean reaction time as a function of transfer group and blocks of pre-transfer trials is illustrated in Figure 16. Figure 16 indicates that neither transfer group nor blocks of trials had a marked effect on reaction time performance.

A 4 x 10 ANOVA was conducted on these data in order to investigate the effects of transfer group (C/C, C/NC, NC/C, and NC/NC) and pre-transfer blocks on reaction time performance. The results of this analysis were consistent with the patterns in the data, and indicated that there were no significant effects of transfer group or blocks of trials. The main effects of transfer group [$F\ (3,12) = 0.17$, $p > .90$] and blocks of trials [$F(9,108) = 0.72$, $p > .65$], and the transfer group x blocks interaction [$F(27,108) = 0.83$, $p > .70$], were all nonsignificant.

Figure 17 shows mean percent correct as a function of transfer group across blocks of pre-transfer trials. Once again, it is apparent that there are no major variations in performance as a function of transfer group or blocks of trials. A 4 x 10 ANOVA which was comparable to the reaction time analysis was performed on the accuracy data. The results were identical with those of the previous analysis, and indicated that neither the main effect of transfer group [$F(3,12) = 1.66$, $p > .20$], nor the main effect of blocks [$F\ (9,108) = 0.88$, $p > .50$], nor the interaction of the two variables [$F\ (27,108) = 0.80$, $p > .70$] was significant.

The failure to find significant effects of blocks or interactions involving blocks in the pre-transfer analyses suggests that subjects had reached a stable level of performance at the conclusion of the CM pre-transfer training trials. The absence of any significant effect

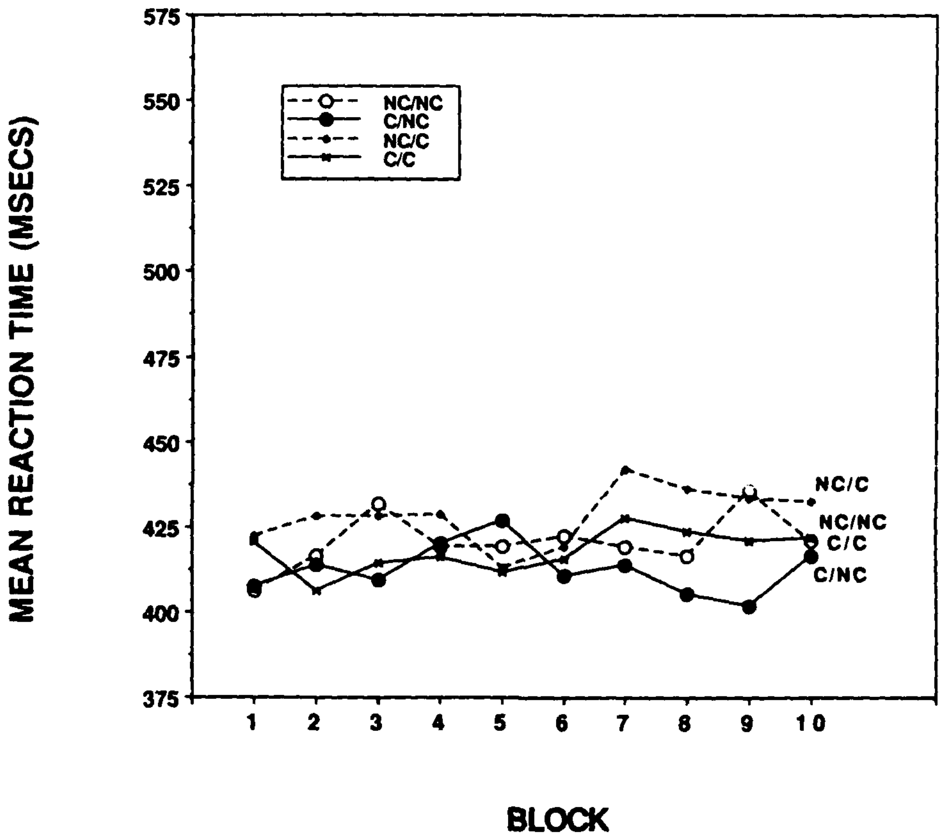


Figure 16. Mean Reaction Time in Blocks of Twenty Trials as a Function of Transfer Group - Experiment 5.

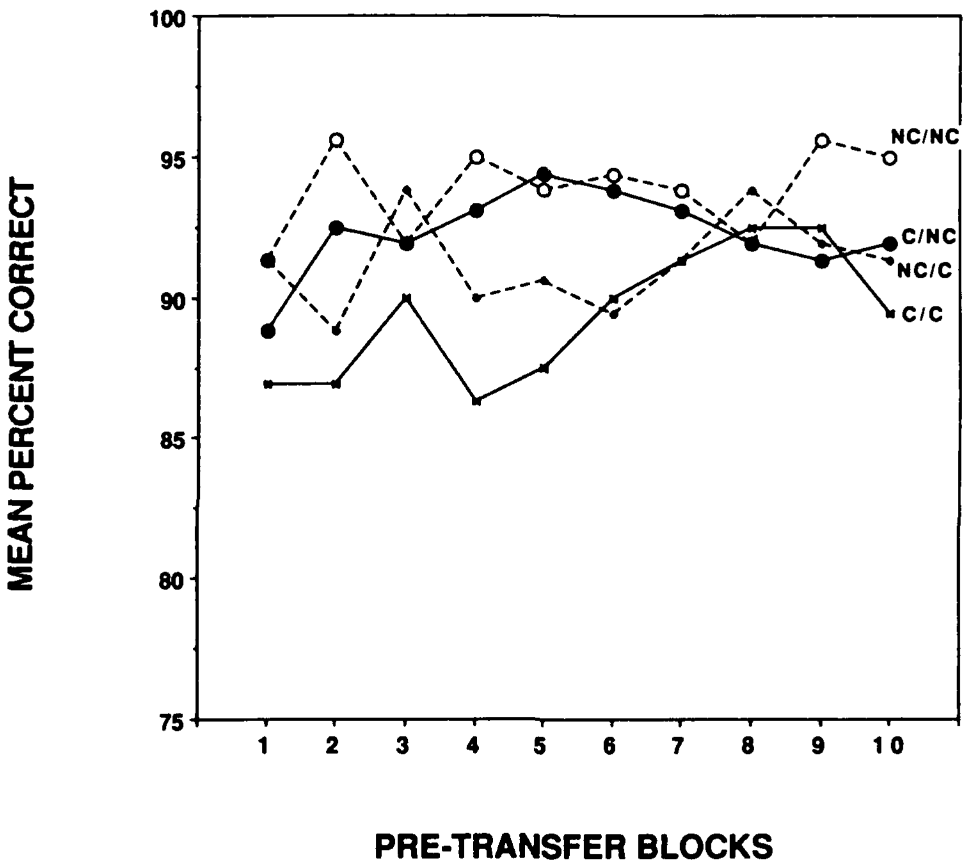


Figure 17. Mean Percent Correct in Blocks of Twenty Trials as a Function of Transfer Group - Experiment 5.

involving transfer group also indicates that there were no significant differences in performance between the groups at the conclusion of training, thereby facilitating interpretation of transfer differences.

Transfer. Difference scores for use in transfer analyses were computed by subtracting each subject's mean RT for the last pre-transfer training block from that subject's mean RT for each transfer block. Figure 18 shows these difference scores. As is apparent in the figure, transfer group influenced performance. The NC/NC group resulted in the lowest difference scores, and maintained performance at the pre-transfer baseline level. The C/NC and C/C groups resulted in the poorest transfer performance, and the difference between these groups and the NC/NC control remained fairly consistent throughout transfer. After an initial increase in reaction time, the performance of the C/NC group improved and approximated the levels associated with the NC/NC group.

Difference score data were analyzed with a 4 x 10 ANOVA which included transfer group (C/C, NC/C, C/NC, NC/NC) and blocks of transfer trials. The main effect of transfer group was marginally significant [$F(3,12) = 3.33$, $p < .06$], whereas the main effect of blocks [$F(9,108) = 0.83$, $p > .50$] and the transfer group x blocks interaction [$F(27,108) = 0.57$, $p > .95$] were non-significant.

Figure 19 illustrates difference scores as a function of transfer group across the 10 blocks of transfer, and shows the overall differences in transfer group performance that were reflected in the marginally significant effect reported above. It is clear that the largest transfer

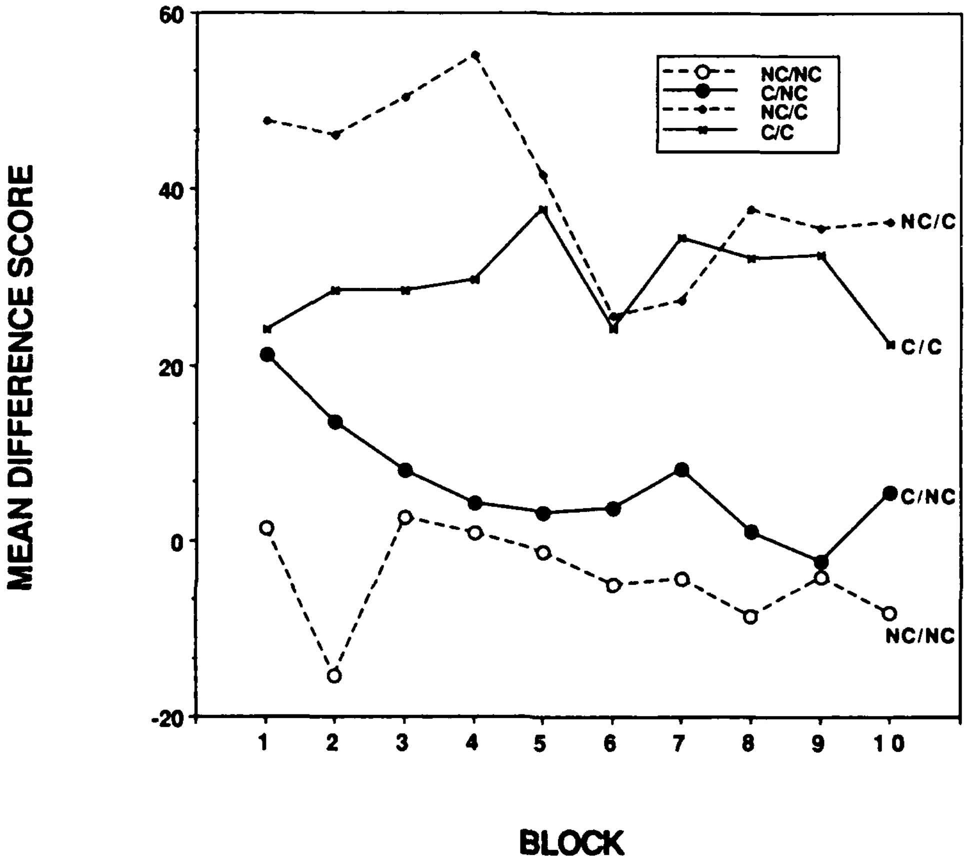


Figure 18. Mean Difference Scores as a Function of Transfer Group and Blocks of Twenty Transfer Trials - Experiment 5.

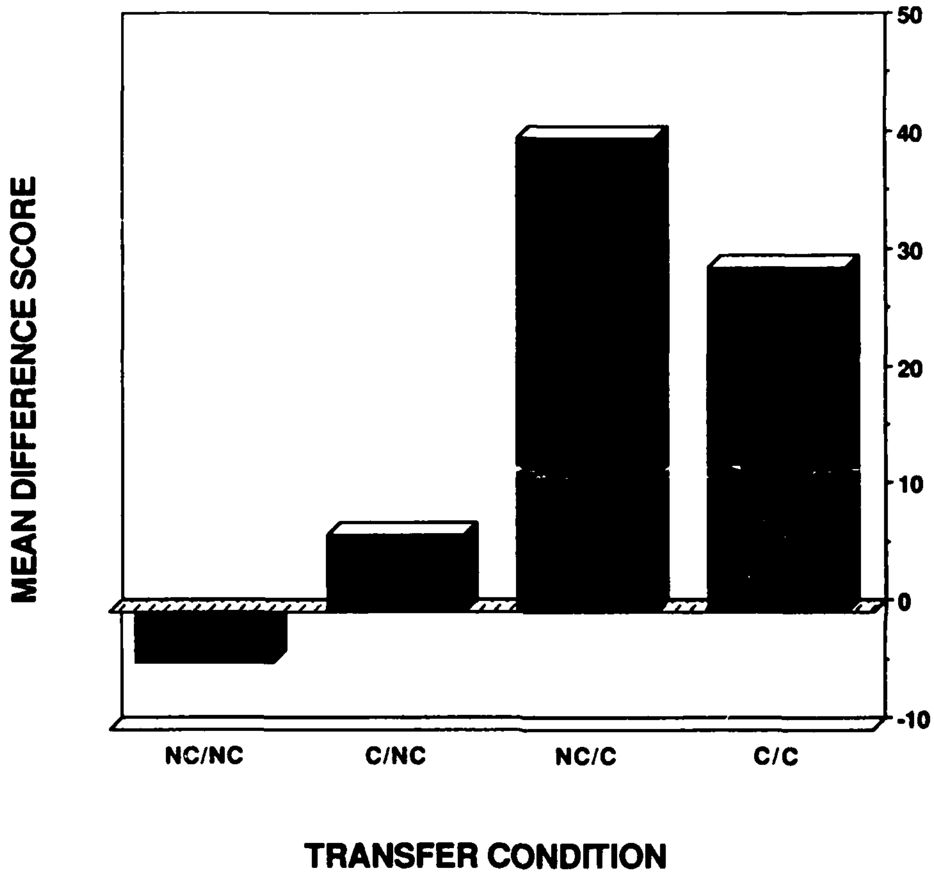


Figure 19. Mean Reaction Time Difference Scores as a Function of Transfer Group - Experiment 5.

penalties were associated with the NC/C and C/C groups, which underwent a change in the sequence sets at transfer. The performance decrement in the C/NC group, which received only a case switch manipulation, is considerably less than that associated with the other two groups. This trend suggests that the effect of the type of physical change used here is minimal relative to changes in the information which is to be processed. For example, the magnitude of the C/NC effect depicted in the figure is only 16% of the magnitude of the NC/C effect. The former represents the pure case switch effect; the latter, the pure sequence set change effect. A Duncan (1955) post-hoc multiple comparison test was performed in order to further investigate the significant effect of transfer groups. Results indicated that the NC/C group differed from the NC/NC control condition, but that none of the other differences were significant.

Mean percent correct responses as a function of transfer group and blocks of transfer are presented in Figure 20. As can be seen in the figure, transfer groups had a minimal effect on response accuracy.

A 4 x 10 ANOVA comparable to that conducted on the reaction time data was performed on the percent correct responses. This analysis failed to demonstrate any significant differences as a function of transfer group or blocks of transfer trials. The main effect of transfer group [$F(3,12) = 1.63$, $p > .20$] and the main effect of transfer blocks [$F(9,108) = 1.03$, $p > .40$] were nonsignificant, as was the two-way interaction [$F(27,108) = 1.35$, $p > .10$].

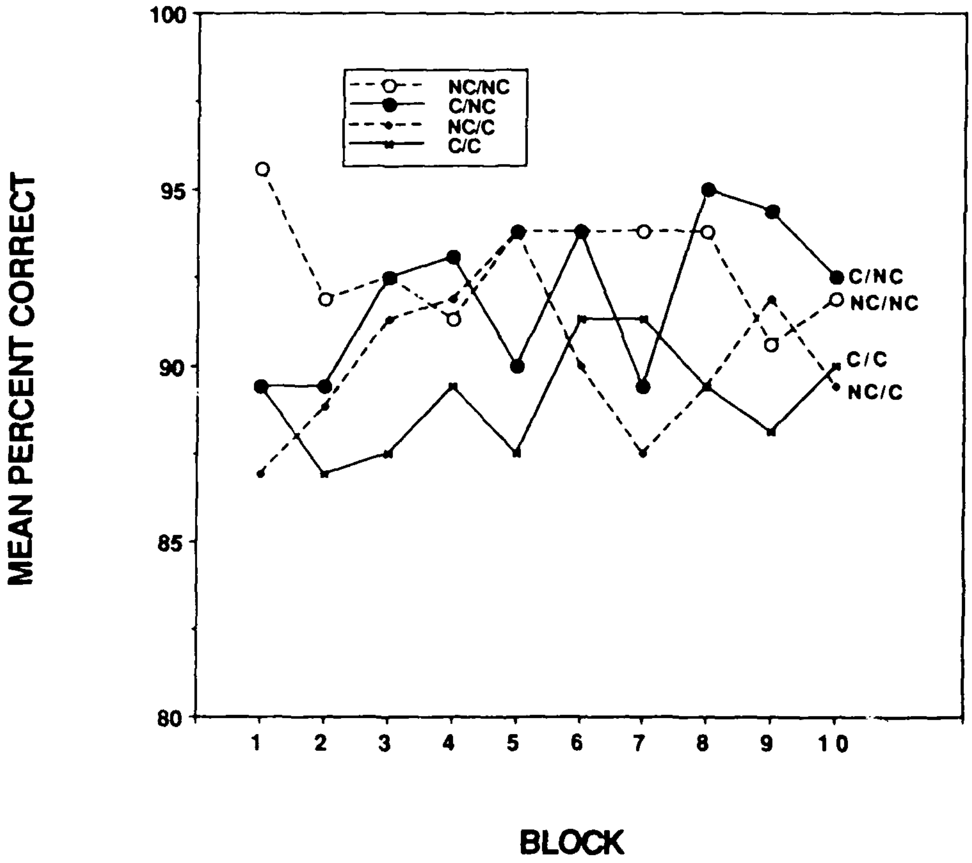


Figure 20. Mean Percent Correct Responses as a Function of Transfer Group and Blocks of Transfer Trials - Experiment 5.

Experiment 6

Transfer of Training with Complex Alphanumeric Materials Under a CM Condition with Similar Target/Distractor Sets

Purpose

Experiments 4 and 5 examined transfer of training in VM and CM conditions with dissimilar target and distractor sets. The purpose of Experiment 6 was to investigate the effect of the three transfer conditions used in the previous two experiments on performance of a CM memory search task with similar target and distractor sets.

The memory task used in this experiment was the same as had been trained in Experiment 3. Once again, the three transfer conditions included (a) a change in the physical characteristics of the sequences that were to be processed, (b) a change in the sequences themselves, and (c) changes in both the physical characteristics and the sequences themselves. A control condition in which no changes occurred was also included. As in the previous two experiments, physical changes were introduced by manipulating the letter case of the sequences that were to be processed by subjects.

Method

Subjects. Subjects were the same 16 University of Dayton students who had participated in Experiment 3. They were paid $5.00 per hour for their participation.

Apparatus. The experiment used the same type of Zenith Data Systems 248 computer and Zenith ZCM-1490 high-resolution color monitor used in Experiment 3. Responses were made on the same arrow keys of a standard expanded IBM-compatible keyboard as used previously. Auditory feedback concerning performance levels was once again presented to subjects through Realistic Nova-16 headphones.

Procedure. Subjects performed the same type of memory search task as that performed in Experiment 3. On each trial, subjects were presented with a memory set of four sequences on the computer CRT screen. These sequences remained on the screen until the subject pressed a designated key on a computer keyboard. At this point, a fixation cross appeared in the middle of the screen for 500 ms. The fixation cross was replaced by a single test sequence, which was displayed for a maximum of 2 seconds or until the subject responded.

Subjects were again instructed to rapidly determine whether or not the test sequence was a member of the previously presented memory set, and to respond "yes" or "no" by pressing a labeled response button on the keyboard. One-half of the target sequences in each block of trials were members of the memory set; the other sequences were not members of the set. Two dependent measures, reaction time and response accuracy, were collected. The 90% criterion level used in Experiment 3 was maintained in this experiment.

The same visual and auditory feedback provided to subjects in Experiment 3 was presented at the completion of each trial. Incorrect responses were followed by a "Wrong Response" message on a red background, and a tone. A correct response was followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence for reaction times that were below 400 ms.

Summary feedback which was identical in format to that of Experiment 3 was provided at the completion of each session. This feedback summarized reaction time and accuracy performance levels from each of the previous sessions. Feedback information which specified four proficiency levels was again provided as an additional aid to subjects in evaluating changes in their reaction times.

The experiment was divided into two phases: (a) pre-transfer and (b) transfer. The purpose of the pre-transfer phase was to establish a performance baseline that could be used to assess levels of transfer in the subsequent phase, and to provide practice to the subjects in performance of the sequence search task under the memory set size four condition alone.

Subjects completed two sessions of pre-transfer performance on the day following the completion of Experiment 3. Each pre-transfer session included 10 blocks of 20 trials each, for a total of 400 pre-transfer trials. Memory set size was held constant at four items. These pre-transfer sessions were performed with the same target and distractor sequence sets in the same letter case as those the particular subject had trained on in Experiment 3. Four of the sixteen subjects therefore continued with similar target/distractor set 1 presented in uppercase letters (S1-U); four subjects, with similar target/distractor set 1 presented in lowercase letters (S1-L); four subjects, with similar target/distractor set 2 presented in uppercase letters (S2-U); and four subjects, with similar target/distractor set 2 presented in lowercase letters (S2-L). The same CM target/distractor mapping that had been used in Experiment 3 was used throughout this experiment.

After completion of the pre-transfer phase, each subject was transferred to one of four conditions: (a) Change/Change (C/C), (b) No Change/Change (NC/C), (c) Change/No Change (C/NC), or (d) No Change/No Change (NC/NC). As in the previous experiments, the first designation refers to whether the letter case of the transfer materials represented a change or no change from the pre-transfer condition, and the second designation indicates whether the transfer sequences represented a change in sequence sets from pre-transfer.

In the C/C condition, four subjects were presented with new sequences in a different letter case than in pre-transfer. In the NC/C condition, four subjects were presented different sequences in the same case as in pre-transfer. Subjects in the C/NC condition were presented with the same sequences as in pre-transfer but in a different letter case. NC/NC transfer subjects continued to perform with exactly the same materials as during pre-transfer. Each of the four subjects in each transfer condition was drawn from one of the four pre-transfer groupings (S1-U, S1-L, S2-U, S2-L). Therefore, all target/distractor sets and letter case conditions were equally represented in each transfer group. Examples of the type of letter sequences used in each transfer condition are included in Appendix E.

Because of changes that occurred in the letters which made up the sequences, all conditions which involved a manipulation of the content of the sequences also involved a change in the physical features of the letters that were to be processed. Therefore, although the C/NC group represented a pure change in the physical characteristics of the information to be processed, the NC/C and C/C groups also involved some changes in the physical features of the sequences. The latter group included the physical feature changes associated with both the sequence changes and the letter case switch.

The transfer phase for all subjects consisted of 10 blocks of 20 trials each, for a total of 200 trials.

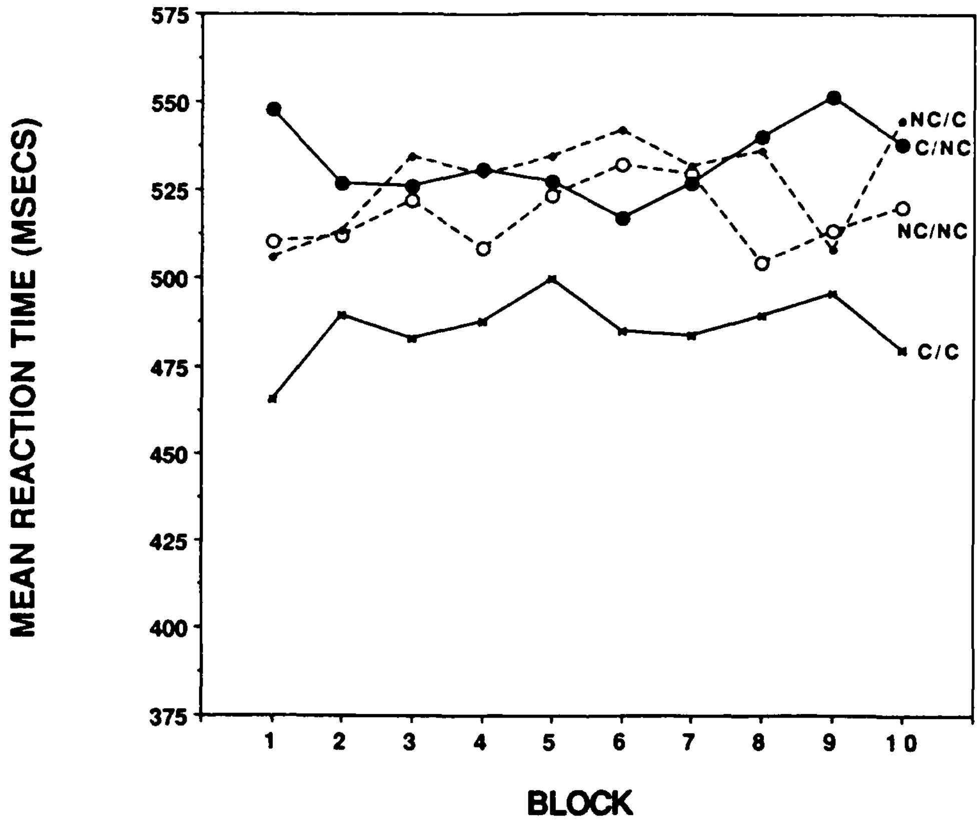
Design. Two independent variables were included in the design: (a) blocks of pre-transfer or transfer trials, and (b) transfer group (C/C, NC/C, C/NC, NC/NC).

Results

Pre-Transfer. Pre-transfer and transfer data were analyzed separately. In each case, correct responses in blocks of 20 trials were used in the data analyses.

Figure 21 shows mean reaction time as a function of transfer group across blocks of pre-transfer trials. As shown in the figure, neither transfer group nor pre-transfer trial blocks substantially affected mean reaction time.

A 4 x 10 ANOVA was conducted on these data in order to investigate the effects of transfer group (C/C, C/NC, NC/C, and NC/NC) and pre-transfer blocks on reaction time performance. This analysis indicated that there was no main effect of transfer group [$F(3,12) = 0.80$, $p > .50$], no main effect of pre-transfer blocks [$F(9,108) = 0.33$, p



<u>Figure 21</u>. Mean Reaction Time in Blocks of Twenty Trials as a Function of Transfer Group - Experiment 6.

>.95], and no transfer x block interaction [$F(27,108) = 0.59$, $p > .90$].

Figure 22 shows mean percent correct as a function of transfer group across blocks of pre-transfer trials. Once again, it is clear that neither the transfer group nor the trial blocks variable substantially affected performance.

A 4 x 10 ANOVA was performed on these data to examine the effects of transfer group (C/C, C/NC, NC/C, and NC/NC) and pre-transfer blocks on the accuracy of performance. This analysis confirmed the trends noted in the figure, and failed to demonstrate any significant effects. Neither the main effect of transfer group [$F(3,12) = 0.81$, $p > .50$], the main effect of blocks [$F(9,108) = 0.64$, $p > .75$], nor the transfer group x blocks interaction [$F(27,108) = 1.01$, $p > .45$] proved to be reliable.

The lack of significant effects of blocks or interactions involving blocks in the pre-transfer analyses suggests that subjects had reached a stable level of performance at the conclusion of training. The absence of any significant effect involving transfer group also indicates that there were no differences in performance between the groups at the conclusion of training, thereby facilitating interpretation of transfer differences.

Transfer. Difference scores for use in transfer RT analyses were computed by subtracting each subject's mean RT for the last of 10 pre-transfer training blocks from that subject's mean RT for each transfer block. These difference scores are presented in Figure 23. As is clear from the figure, transfer group had a substantial impact on reaction

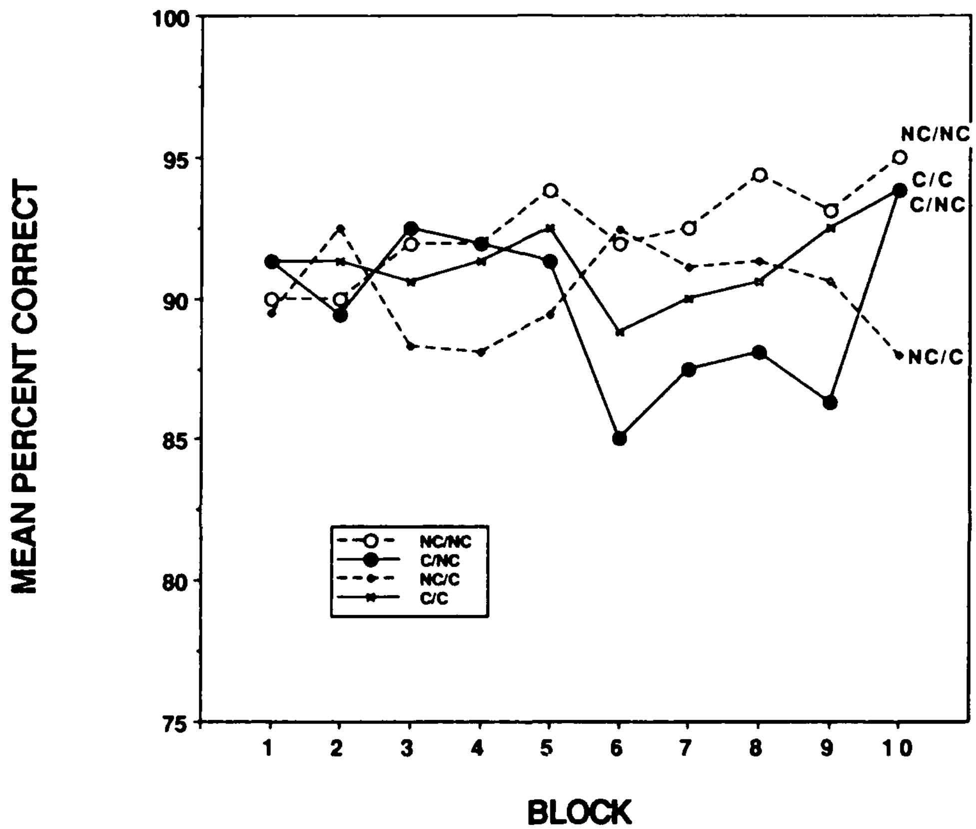


Figure 22. Mean Percent Correct in Blocks of Twenty Trials as a Function of Transfer Group - Experiment 6.

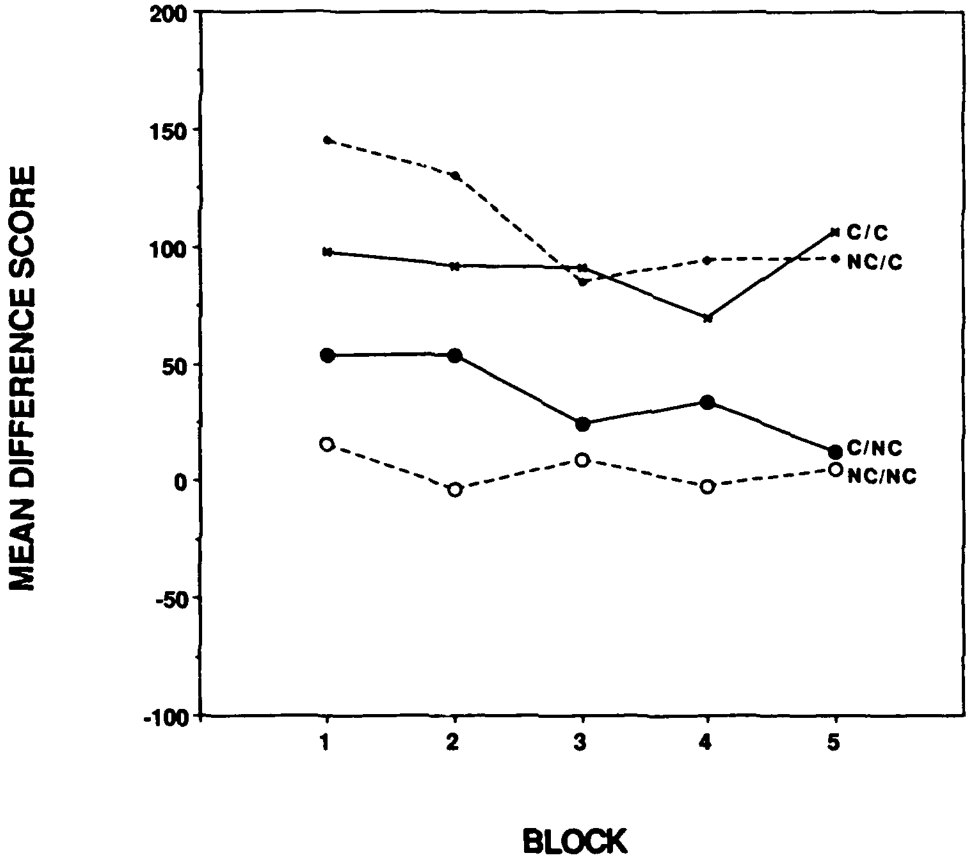


Figure 23. Mean Difference Scores as a Function of Transfer Group and Blocks of Twenty Transfer Trials - Experiment 6.

time. The most notable trends concern the NC/C and C/C groups, in which sequence sets were changed from those that had been previously trained. These groups demonstrated the highest difference scores.

The difference score data shown in Figure 23 were analyzed with a 4 x 5 ANOVA which included transfer group (C/C, NC/C, C/NC, NC/NC) and blocks of transfer trials. Transfer group represented a between-subjects variable in this analysis, whereas transfer blocks was a within-subjects variable. This ANOVA demonstrated a significant main effect of transfer group [$F(3,12) = 3.65$, $p < .05$] and a marginally significant effect of transfer blocks [$F(4,48) = 2.40$, $p < .07$]. The transfer group x transfer block interaction failed to reach significance [$F(12,48) = 0.89$, $p > .55$].

Mean difference scores as a function of transfer group across all transfer trials are depicted in Figure 24, and show the basis for the main effect of transfer group reported above. As was the case in Experiment 5, the ordering of transfer groups indicates that the largest decrements in transfer performance occurred in the NC/C and C/C groups which underwent changes in the sequences that were processed at transfer. Once again, the effect of the letter case switch is minimal in comparison with the sequence change, suggesting that physical changes are relatively unimportant with the types of materials that were included here. In this instance, the magnitude of the pure case switch effect (C/NC) was 32% of the magnitude of the pure sequence change (NC/C) effect. A Duncan (1955) post-hoc multiple comparison test which was conducted to investigate the significant transfer group effect indicated that the

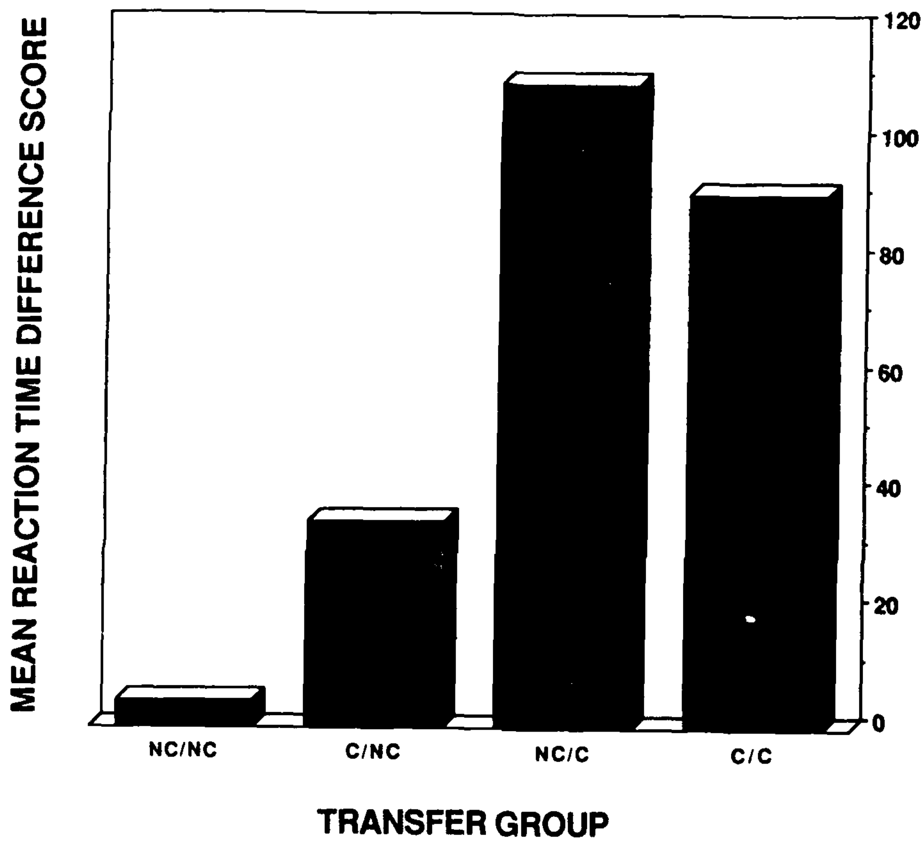


Figure 24. Mean Reaction Time Difference Scores as a Function of Transfer Group - Experiment 6.

NC/C and C/C groups differed significantly from the NC/NC control, but that no other differences were reliable.

Percent correct responses as a function of transfer group and transfer blocks are shown in Figure 25. As is apparent from the figure, transfer group had an influence on response accuracy. As was expected, the highest accuracy levels were maintained by the NC/NC control group. The most notable trend among the other groups is the tendency for the C/C and C/NC groups to exhibit a lower percent correct than the NC/C group.

A 4 x 5 ANOVA was conducted on the percent correct data illustrated in Figure 25, in order to assess the effects of transfer group and trial blocks on response accuracy. The main effect of transfer group was significant [$F(3,12) = 4.15$, $p < .04$], as was the main effect of transfer blocks [$F(4,48) = 3.10$, $p < .03$]. The transfer group x blocks interaction [$F(12,48) = 1.08$, $p > .35$] was not significant. A comparable 4 x 5 ANOVA on percent correct difference scores was also conducted and produced the same pattern of results.

Figure 26 illustrates mean percent correct as a function of transfer group, and shows the basis of the main effect of transfer that was reported above. The pattern of data in this figure, when considered with the pattern shown in Figure 24, indicates that accuracy and reaction time should be jointly considered in assessing the effects of transfer in this instance. The C/C group, for example, had lower difference scores than did the NC/C group on the reaction time measure, but exceeded the NC/C group in errors. This pattern in the results suggests that reaction times in the C/C group might have been more comparable to

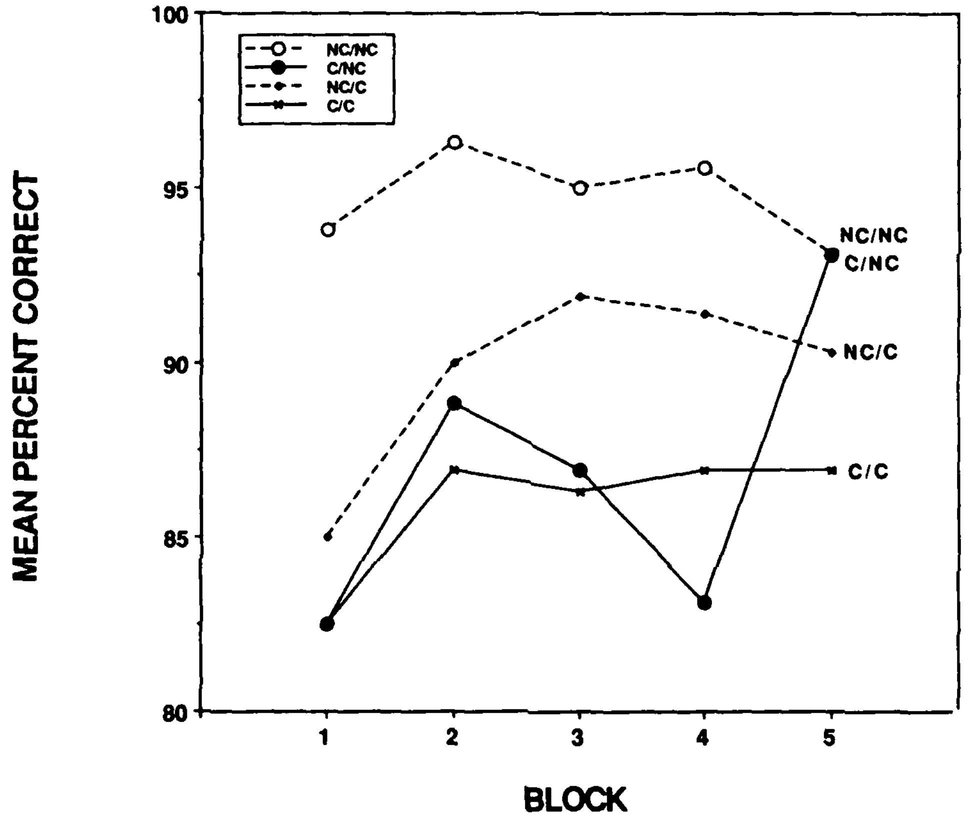


Figure 25. Mean Percent Correct as a Function of Transfer Group and Blocks of Transfer Trials - Experiment 6.

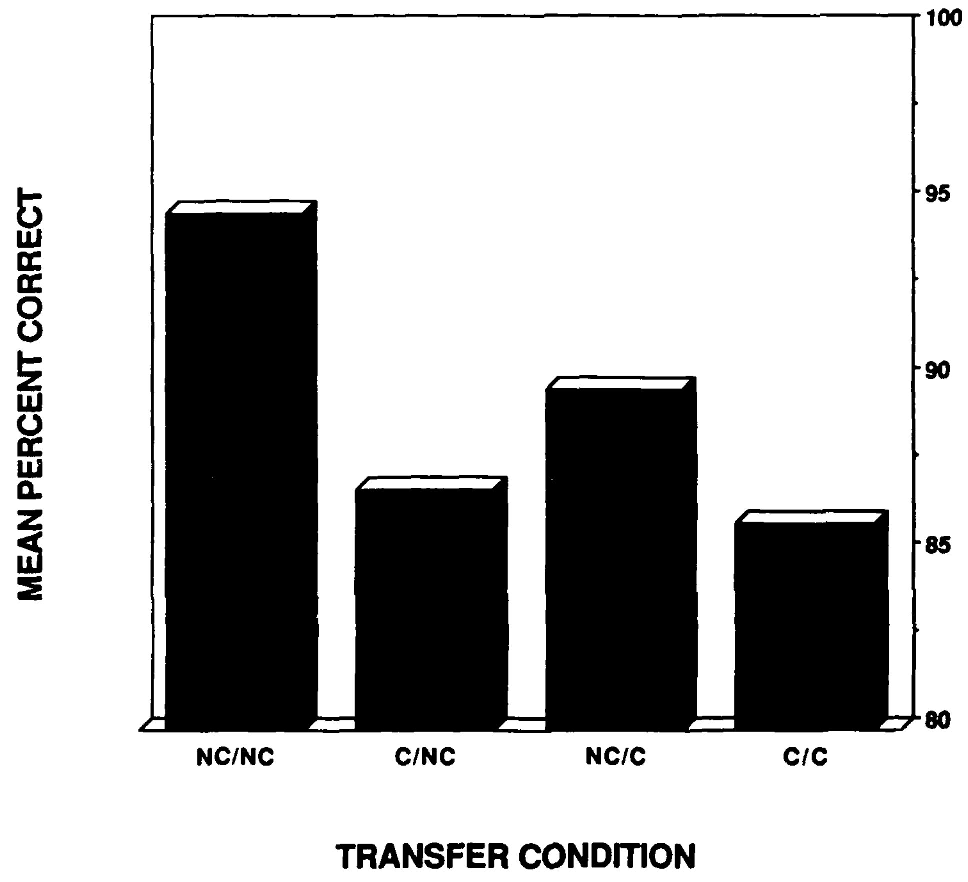


Figure 26. Mean Percent Correct as a Function of Transfer Group - Experiment 6.

those of the NC/C group if accuracy had not differed between the two groups.

Comparison of Similar and Dissimilar Target/Distractor Set Conditions

Comparison of the results of Experiments 5 and 6 permits some assessment of the impact of target/distractor discriminability on the pattern of transfer which results with the introduction of physical changes and manipulations of the sequence sets which are to be processed.

Figure 27 presents mean reaction time difference scores as a function of transfer group and CM condition from Experiments 5 and 6. As shown in the figure, the pattern of performance at transfer is quite consistent across the two experiments. The most notable difference is the magnitude of the effect of physical change and sequence manipulations across the CM conditions, with the CM similar condition (Experiment 6) exhibiting generally more pronounced effects than the CM dissimilar condition (Experiment 5). One factor which may have contributed to these magnitude variations is the difference in the rate of acquisition in the CM similar and CM dissimilar conditions that was noted in Experiments 2 and 3. During acquisition, the CM dissimilar condition showed a consistent advantage in reaction time from the first through the last session of training, and also resulted in less pronounced effects of variations in memory set size than was the case in the CM similar condition. These differences in acquisition rate would have also been expected to be present at transfer in the NC/C and C/C conditions, and could have resulted in a lower magnitude of transfer effect across the transfer trials.

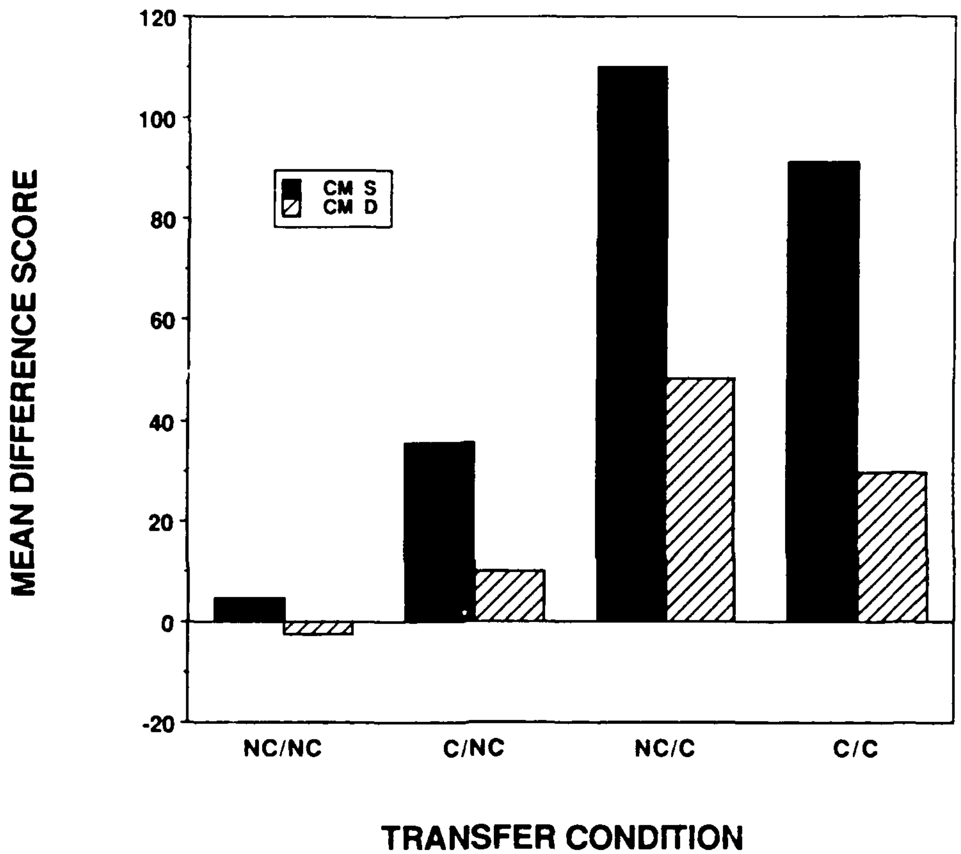


Figure 27. Mean Reaction Time Difference Scores as a Function of Transfer Group and CM Condition-Experiment 5 (Consistent Mapping-Dissimilar) versus Experiment 6 (Consistent Mapping - Similar).

A 2 x 4 x 5 ANOVA was performed on reaction time difference scores in order to evaluate the effects of CM condition (CM-S versus CM-D), transfer group (NC/NC, NC/C, C/NC, C/C), and blocks of transfer trials on the reaction time difference scores shown in Figure 27. This analysis verified the trends noted above, and indicated that the main effects of CM condition [$F(1,24) = 7.85$, $p < .02$] and transfer group [$F(3,24) = 6.48$, $p < .01$] were significant, but that all other effects were not. A similar analysis performed on response accuracy data across the two CM conditions demonstrated a significant main effect only for transfer group [$F(3,24) = 6.05$, $p < .01$]. This effect represents the trend of higher accuracy in the NC/NC groups in both CM conditions. All other accuracy effects were non-significant.

In order to examine the pattern of transfer across CM conditions without the magnitude differences noted above, mean RT difference scores in the CM similar condition and mean RT difference scores in the CM dissimilar condition were converted to standard scores. These standard difference scores are presented as a function of transfer group and CM condition in Figure 28. As is readily apparent from the figure, the pattern of transfer group effects is remarkably similar across the two experiments. These trends suggest that the NC/C and C/C conditions resulted in the highest difference scores or lowest levels of performance, and also indicate that the effect of letter case switch was relatively minor in each case.

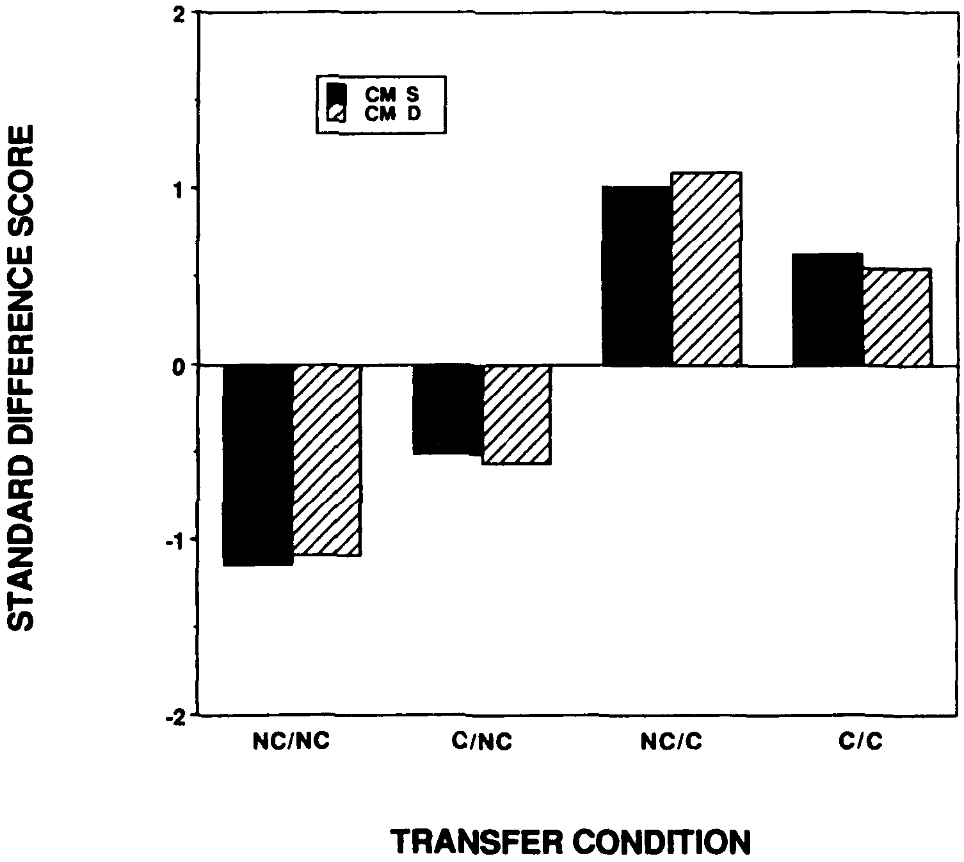


Figure 28. Standard Reaction Time Difference Scores as a Function of Transfer Group and CM Condition - Experiment 5 (Dissimilar) versus Experiment 6 (Similar).

General Discussion

The pattern of transfer exhibited in Experiments 5 and 6 indicates that the physical change manipulation used in the current work had relatively minor effects on transfer performance with both types of target/distractor sets, and suggests that CM performance with this type of alphanumeric material is somewhat robust with respect to such changes. This relatively minor effect of case switch is consistent with the results of Hale (1988), who reported that the magnitude of a case switch effect was approximately 22% that of a change in the semantic materials that were to be processed under CM category search. In the present experiments, case switch resulted in an effect that was only 16% of the magnitude of a letter sequence change in the CM condition in Experiment 5, and 32% of the magnitude of a letter sequence change under CM mapping in Experiment 6. As indicated earlier, it was expected that case switch might show a more dramatic effect with the type of alphanumeric materials used in these experiments as compared to the semantic materials used by Hale (1988). However, comparison of the present results with those of Hale do not indicate any appreciable differences in the magnitude of the effects obtained with the different materials.

One important area for additional research regarding transfer of complex alphanumeric materials concerns the effects of other types of physical manipulations on operator performance. The case switch manipulation used here had produced significant effects on transfer performance in previous investigations (Hale, 1988; Lane & Kleiss, 1985), but it would be desirable to explore the effects of other and potentially more dramatic physical changes on the types of alphanumeric information investigated here. As noted above, applications of part-task trainers to establish some level of automatic processing in components of C2 operator tasks might involve less-than-perfect fidelity of information presentation, and further exploration of the boundaries of permissible physical changes (e.g., size, color, and font of letters) could contribute to the design of such trainers.

An additional area for future research concerns the transfer that would be obtained with the types of materials used here in a visual rather than a memory search paradigm. Visual search requires that subjects search for a single target item among a number of distractor items, and is relevant to some important information processing functions required of C2 system operators (Eggemeier et al., 1988). The results of the current work with a memory search paradigm appear somewhat inconsistent with those of Lane and Kleiss (1985), who reported significant decrements in performance and loss of load reduction effects with case switch manipulations in a single-letter classification task. One potentially important difference between the current work and that of Lane and Kleiss is that the latter employed a combined memory and visual search paradigm rather than the pure memory search paradigm used here. This suggests the possibility that physical changes may have a more substantial impact on the visual search component of operator tasks, and underscores the desirability of additional transfer work within a visual search paradigm.

In addition to work with other physical manipulations and with visual search paradigms, future investigations should examine the influence of changes in individual components of the complex alphanumeric sequences on transfer. Previous research with automatic processing (e.g., Hale, 1988; Hassoun & Eggemeier, 1988; Schneider & Fisk, 1984) has demonstrated positive transfer to untrained exemplars of trained semantic categories in a category search paradigm, indicating that the performance benefits associated with trained materials can extend to similar but untrained materials. Because of its implications for the design of training programs for C2 operators, it is important to determine if the positive transfer demonstrated with semantic materials will also occur with the complex alphanumeric information investigated in the present experiments. Follow-on research should examine the transfer of trained letter sequences of the type used here to similar sequences which differ in one or more letters from the trained materials. If positive transfer results, it would suggest that operator training programs concerned with complex alphanumeric materials could be designed to make use of previous practice with similar materials.

Future transfer work should also be conducted with the types of spatial pattern information that were investigated in Experiment 1 in this series. This research should investigate the effect of various physical change (component elements making up the pattern, pattern orientation, etc.) on transfer. Another important issue to be addressed by future work with spatial pattern information is transfer within categories of patterns which depict different types of target movement (e.g., acceleration, deceleration). Such work would build on the acquisition data that were developed in Experiment 1, and could be very important to eventual applications of current training procedures to Air Force systems requiring the processing of spatial pattern information.

IV. SUMMARY AND CONCLUSIONS

The results of the present training experiments indicate that performance levels which are consistent with automatic processing can in fact be developed in tasks which involve two types of information required by operators of Air Force C2 systems. The results support the development of automatic processing not only with spatial pattern information, but with complex alphanumeric information as well. The effect of the discriminability of target and non-target alphanumeric information proved to be an important factor in the levels of performance that were achieved under equivalent levels of training, and therefore represents an important consideration in the development of training programs with these types of materials.

The current research on transfer has also demonstrated that automatic processing of complex alphanumeric materials is relatively unaffected by one type of physical change in the materials that are to be processed. This proved to be the case under CM conditions with both similar and dissimilar target/distractor sets, and is important in indicating that automatic processing with these types of materials is somewhat robust with respect to this type of physical change.

Using the present results as a baseline, future research in the acquisition of automatic processing should be extended to more complex spatial pattern information, and to rule-based consistencies with complex alphanumeric information. In addition, work on the conditions and limits of transfer should be conducted with the type of spatial pattern information which was investigated here, as this type of information and its transfer are critical to applications to many Air Force systems.

In addition to transfer, another very important area for the development of effective training systems concerns the retention of automatic components of tasks. Hodge and Fisk (1989) have recently investigated the retention of automatic components of a semantic category search task. This type of retention work should be extended to include the types of spatial pattern and complex alphanumeric information that were investigated in the present series of experiments.

Such research is essential to a refined methodology for structuring training programs to permit development of automatic processing in components of actual operator C2 system tasks, and should contribute to the successful application of automatic processing principles to high performance skills development.

REFERENCES

Duncan, D.B. (1955). Multiple range and multiple F tests. *Biometrics*, *7*, 1-16.

Eberts, R., & Schneider, W. (1986). Effects of perceptual training of sequenced line movements. *Perception and Psychophysics*, *39*, 236-247.

Eggemeier, F.T., Fisk, A.D., Robbins, R., Lawless, M.T., & Spaeth, R. (1988). *High performance skills task analysis methodology: An automatic human information processing theory approach*. (AFHRL-TP-88-32, AD-B128 366). Wright-Patterson AFB, Ohio: Logistics and Human Factors Division, Air Force Human Resources Laboratory.

Fisk, A.D., Oransky, N.A., & Skedsvold, P.R. (1988). Examination of the role of "higher-order" consistency in skill development. *Human Factors*, *30*, 567-582.

Fisk, A.D., & Schneider, W. (1983). Category and word search: Generalizing search principles to complex processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 181-197.

Fisk, A.D., & Schneider, W. (1984). Consistent attending versus consistent responding in a visual search: Task versus component consistency in automatic processing development. *Bulletin of the Psychonomic Society*, *22*, 330-332.

Hale, S.L. (1988). *The locus of automatic processing in category word search*. Unpublished master's thesis, Wright State University, Dayton, OH.

Hassoun, J.A., & Eggemeier, F.T. (1988, August). *Transfer of automatic processing in category and word search*. Paper presented at the American Psychological Association Annual Meeting, Atlanta, GA.

Hodge, K.A., & Fisk, A.D. (1989). Toward an understanding of skill decay: Retention of automatic components. Paper accepted for presentation at the 1989 Human Factors Society Annual Meeting.

Kramer, A.F., Strayer, D.L., & Buckley, J. (1989). Rules and exemplars: The influence of level of consistency on the development and transfer of automatic processing. Unpublished manuscript, Department of Psychology, University of Illinois, Champaign-Urbana, Illinois.

Lane, D.M., & Kleiss, J.A. (1985). Are automatic attention responses semantically or visually based? Unpublished manuscript, Rice University, Houston, Texas.

Logan, G.D. (1985). Skill and automaticity: Relations, implications, and future directions. Canadian Journal of Psychology, 39, 367-386.

Myers, G.L., & Fisk, A.D. (1987). Application of automatic and controlled processing theory to industrial training: The value of consistent component training. Human Factors, 29, 255-268.

Schneider, W., Dumais, S.T., & Shiffrin, R.M. (1984). Automatic and control processing and attention. In R. Parasuraman and D.R. Davies (Eds.), Varieties of attention (pp. 1-27). New York: Academic Press.

Schneider, W., & Fisk, A.D. (1984). Automatic category search and its transfer. Journal of Experimental Psychology: Learning, Memory, and Cognition, 10, 1-15.

Schneider, W., Vidulich, M., & Yeh, Y. (1982). Training spatial skills for air traffic control. In Proceedings of the Human Factors Society Twenty-Sixth Annual Meeting (pp. 10-14), Seattle, Washington.

Shiffrin, R.M., & Dumais, S.T. (1981). The development of automatism. In J.R. Anderson (Ed.), _Cognitive skills and their acquisition_ (pp. 111-140). Hillsdale, New Jersey: Erlbaum.

Shiffrin, R.M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. _Psychological Review_, _84_, 127-190.

Sternberg, S. (1966). High speed scanning in human memory. _Science_, _153_, 652-654.

Underwood, B.J., & Schultz, R.W. (1960). _Meaningfulness and verbal learning_. Chicago, IL: J.B. Lippincott Co.

APPENDIX A: EXAMPLES OF SPATIAL PATTERN MATERIALS USED IN EXPERIMENT 1

Pattern	Target Movement Represented[1]
o o o o o	Constant Movement, Turn at Initiation
o o o o	Acceleration, No Turn
o o o o o	Deceleration, Turn at Completion

[1] The direction of pattern movement indicated in each case is from left to right.

APPENDIX B: EXAMPLES OF LETTER SEQUENCES USED IN EXPERIMENT 2

Targets	Distractors
DXR	BPK
FLJ	GMB
SKC	WFD
MTW	QNH

APPENDIX C: EXAMPLES OF LETTER SEQUENCES USED IN EXPERIMENT 3

Targets	Distractors
DXR	DXC
FLJ	FTW
SKC	SKR
MTW	MLJ

APPENDIX D: EXAMPLES OF LETTER SEQUENCES USED IN EXPERIMENTS 4 AND 5

Transfer Condition[1]	Pre-Transfer Target/Distractor	Transfer Target/Distractor
NC/NC	DXR/BPK	DXR/BPK
C/NC	DXR/BPK	dxr/bpk
NC/C	DXR/BPK	RKG/NTW
C/C	DXR/BPK	rkg/ntw

[1] In each instance, the first letter designation refers to a Change (C) or No-Change (NC) in letter case from Pre-Transfer to Transfer Conditions, and the second letter to Change (C) or No-Change (NC) in the letter sequences themselves.

APPENDIX E: EXAMPLES OF LETTER SEQUENCES USED IN EXPERIMENT 6

Transfer Condition[1]	Pre-Transfer Target/Distractor	Transfer Target/Distractor
NC/NC	DXR/DXC	DXR/DXC
C/NC	DXR/DXC	dxr/dxc
NC/C	DXR/DXC	RKG/RNH
C/C	DXR/DXC	rkg/rnh

[1] In each instance, the first letter designation refers to a Change (C) or No-Change (NC) in letter case from Pre-Transfer to Transfer Conditions, and the second letter to Change (C) or No-Change (NC) in the letter sequences themselves.

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